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DEPARTMENT OF THE INTERIOR, CANADA  
SIR JAMES LOUGHEED, Minister      W. W. CORY, Deputy Minister  
*Canada.* TOPOGRAPHICAL SURVEYS BRANCH


BULLETIN 44

STANDARDIZATION OF  
MEASURES OF LENGTH AT  
THE LABORATORY OF THE  
DOMINION LANDS SURVEYS

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THOMAS MULVEY  
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## INTRODUCTORY NOTE.

It is the duty of the Surveyor General, as President of the Board of Examiners for Dominion land surveyors, to supply standard measures of length to Dominion land surveyors. The law respecting such measures is as follows:—\*

“The measure of length used in the surveys of Dominion lands shall be the Dominion measure of length defined by the Weights and Measures Act, and every Dominion land surveyor shall be in possession of a subsidiary standard thereof tested and marked as correct by the Surveyor General, which subsidiary standard shall be furnished to him by the secretary of the Board on payment of the fee fixed therefor by the Act, and notwithstanding anything to the contrary in the Weights and Measures Act, such subsidiary standard shall not require any test, stamp, inspection or verification other than is required by this Act; and all Dominion land surveyors shall from time to time regulate and verify by such standard the length of their chains and other instruments for measuring lengths; and the said standard measure shall be returned to the secretary of the Board to be tested at least once every four years.”

The Metrological Section of the Surveys Laboratory was established to supply these standard measures and to test them from time to time as directed by law.

The greater accuracy now obtained in the rapid measurement of base lines and in other chaining by the use of steel and invar tapes has made it necessary to provide means whereby these measures may be calibrated with a high degree

\*Sect. 35 of 7 and 8 Ed. VII., Chap. 21.

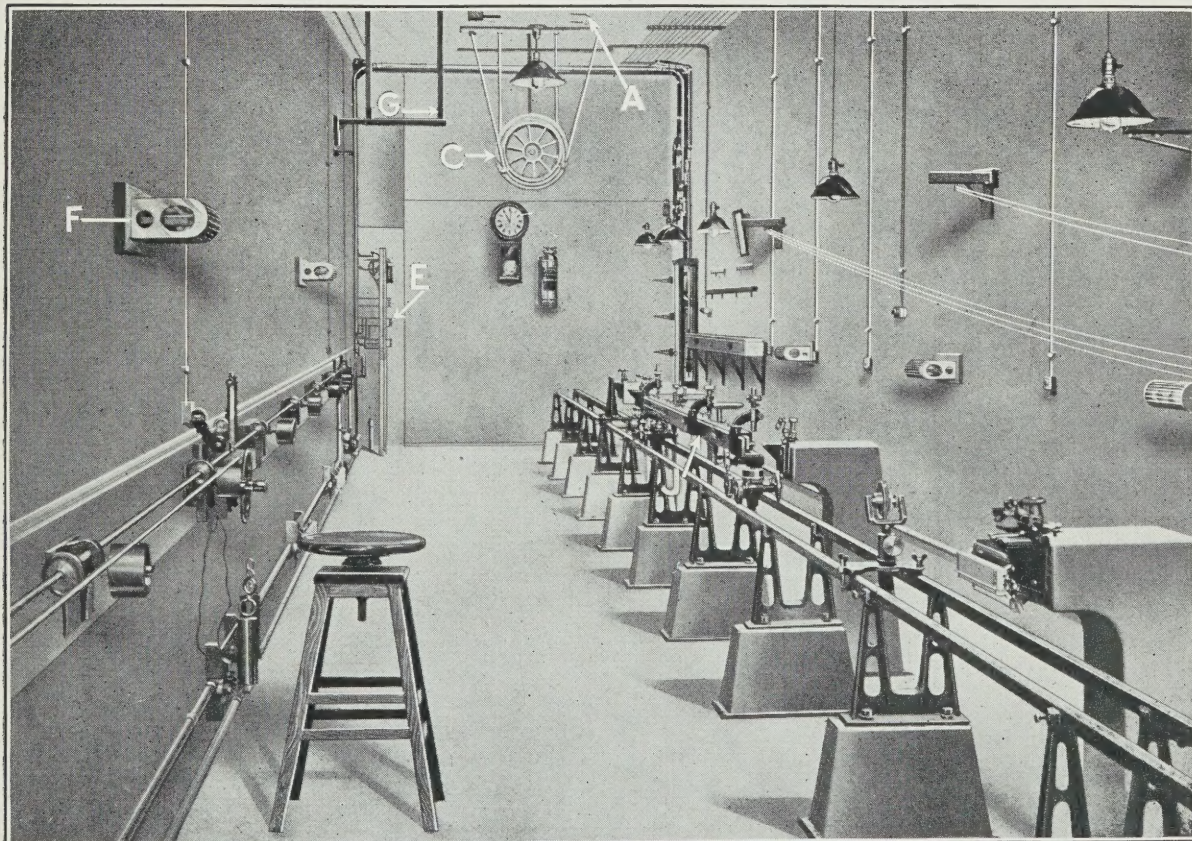


FIG. 1—Interior of Testing Room (Looking North)

Base on the right with 4<sup>m</sup> rule carriage in position opposite bench marks on the piers.  
Tape comparator on the left.

A—Air outlet, C—Blower fan, E—Switchboard, F—Thermometer cages, G—Tape hangers.

of precision. This requires the provision of a base which can be checked from time to time by standard measures, these being periodically compared with the International Metre at Paris and with the Canadian Yard.

After giving due consideration to the various bases in existence and consulting with M. C. E. Guillaume, of the International Bureau, Paris, and other authorities, it was decided to construct a comparator base 32 metres long of the permanent benchmark type, with the benchmarks rigidly fixed to concrete piers. The necessary apparatus was made by La Société Genevoise d'Instruments de Physique.

Means are provided to intercompare the rules used as standards in connection with the measurements, and to verify on the base standard tapes of any length. A tape comparator is also available for rapidly but accurately comparing tapes with the Laboratory standards. The flexibility and design of the apparatus, together with the possession by the Laboratory of the necessary standards, permits the standardization of measures of all kinds.

### BUILDING

The base and subsidiary apparatus here described is contained in a neat one-story brick building of special construction, erected in 1913 on MacKay Street, Ottawa. The testing room, the interior of which is shown in Figs. 1 and 2, is 150 feet long by 10 feet 6 inches wide with 12 foot ceiling; at the entrance is a small vestibule and cloakroom. The control and measurement of temperature being important factors when determining the length of metal tapes, the walls, floor and roof are exceptionally well insulated, while openings to the outside air are reduced to a minimum consistent with efficient ventilation.

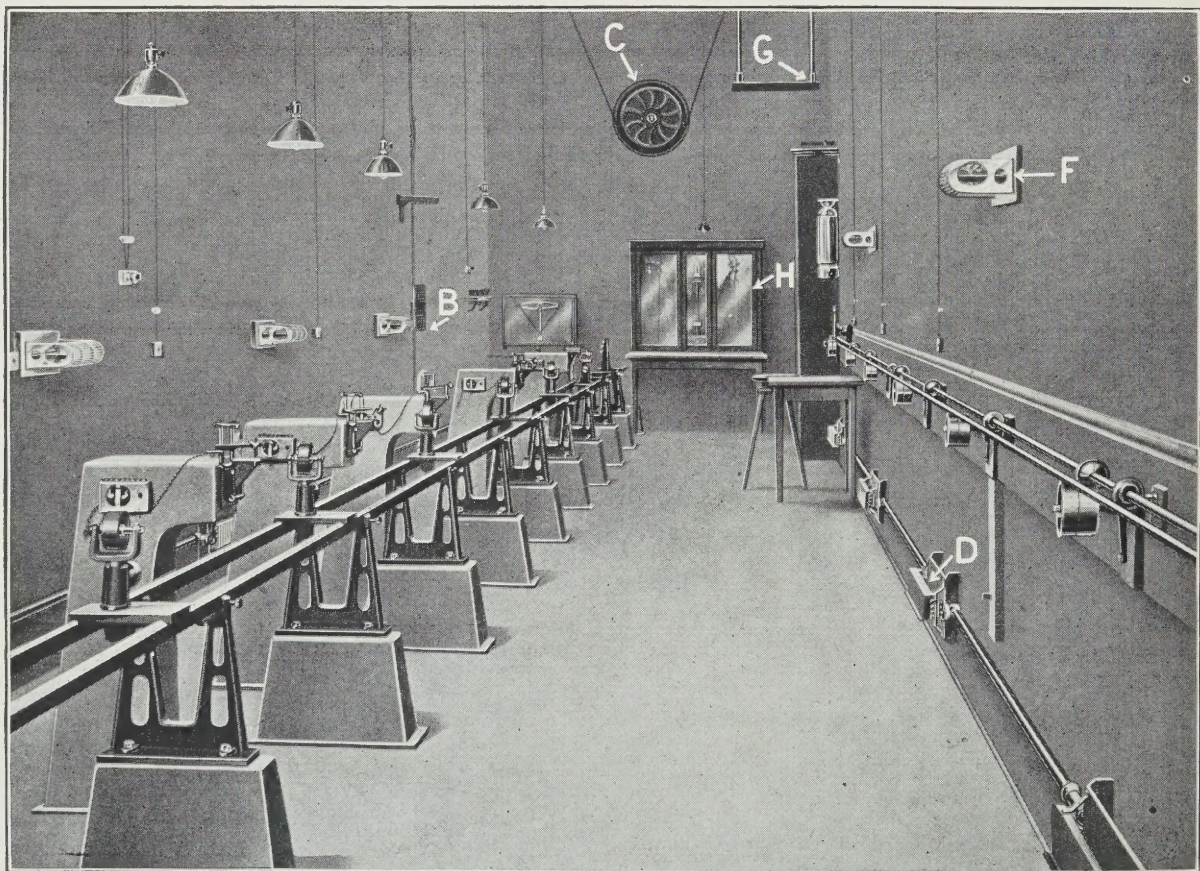


FIG. 2—Interior of Testing Room (Looking South)

Base on the left with pulleys for supporting tapes in position on the rails.  
Tape comparator on the right.

B—Air inlet, C—Blower fan, D—Electric heaters, F—Thermometer cages, G—Tape hangers, H—Precision balances.

A section of the room is shown in Fig. 3. The walls are four feet thick and composed of the following in order—five thicknesses of brick, a one-inch air space, one inch wood sheeting, tar paper, 18 inches of shavings, tar paper, one inch wood sheeting, a four inch air space, and finally, double sheeting. Over the ceiling is a two foot layer of shavings separated from the roof by an air space. Beneath the floor, shavings are laid to a depth of 12 inches, the remaining space above the rock having been filled in with cinders. There are no windows, the lighting being entirely by artificial means. The only entrance is located at the north end. It consists of two doors, the inner one being of the refrigerator type, with a space of 4 feet between the two. To provide for ventilation there are four outlets A, Fig. 3, along the centre of the ceiling, with two air intakes B, one at each end of the room, located at the base of the walls. All these ventilators may be opened to any desired amount or completely closed.

In order to circulate the air and maintain a uniform temperature throughout the testing room, a blower fan C, of .25 H.P., is suspended from the ceiling, near each end of the room. The temperature is controlled (except in extremely

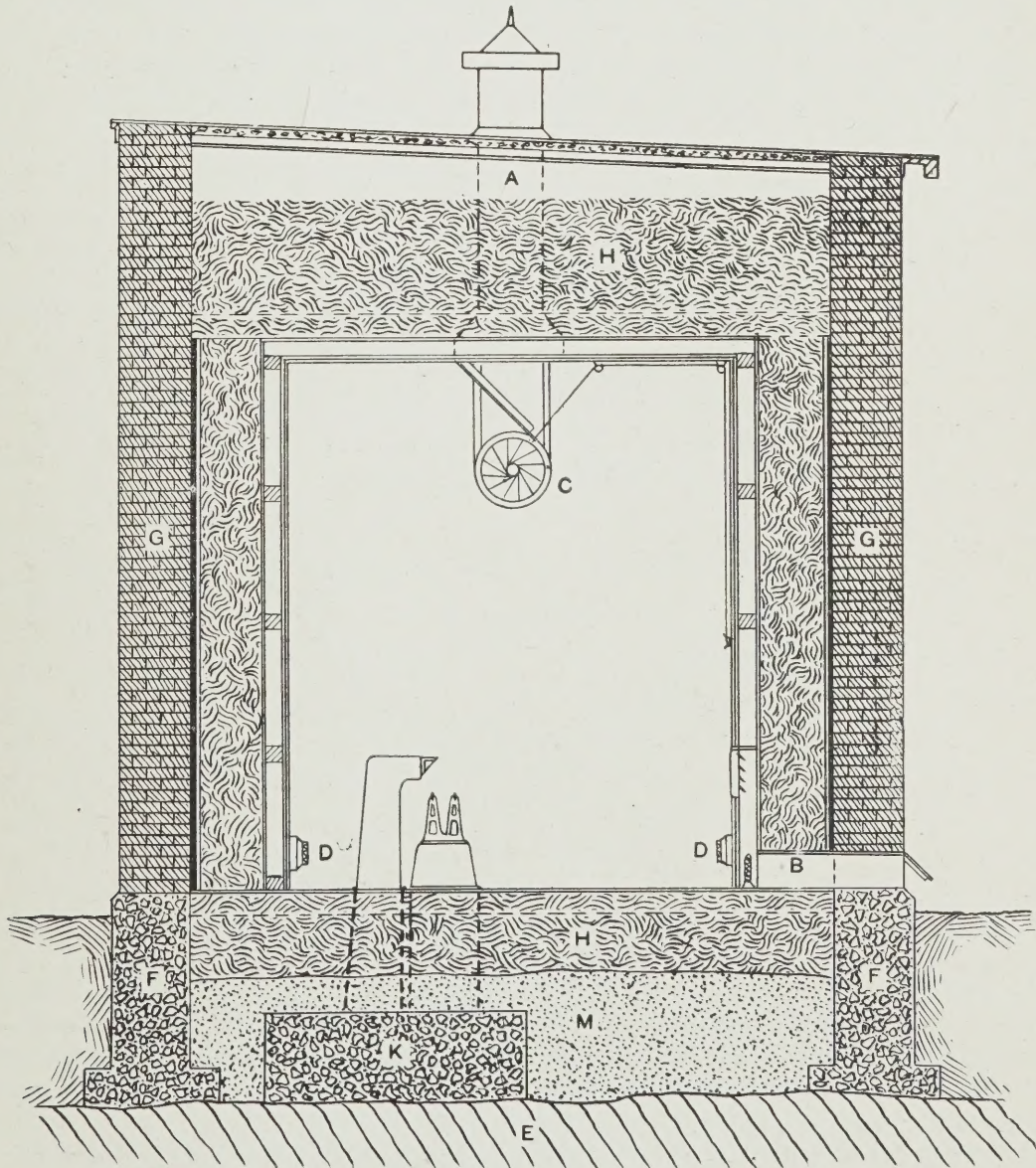


FIG. 3—Testing Room  
Section through VV Fig. 11

A—Air outlet, B—Air inlet, C—Blower fan, D—Electric heaters, E—Rock, F—Concrete foundation, G—Brick walls, H—Shavings, K—Concrete monolith supporting the piers, M—Cinders.

hot weather) by means of twenty electric radiators D. These are distributed uniformly around the walls, near the floor, and are on two separate circuits. Each set of radiators may be regulated to give three degrees of heat. An electric heater is also placed in each intake to control the temperature of the air admitted to the room. The heaters are all controlled from a switchboard E, Fig. 1, near the entrance to the testing room. This board has two panels, from either of which any, or all, of the heaters may be fed. The bus-bars of the lower panel are fed through a Johnson Heat Regulator which is controlled from a thermostat near the centre of the room. This provides an automatic regulation for the circuits connected to this panel, which are thrown in and out of action by the thermostat. To prevent the regulator from acting at too frequent intervals, with the consequent alternate rapid heating and cooling of the room, that would occur if the whole of the heating current were controlled by the thermostat, it is the practice to connect a portion of the heaters in use to the upper panel of the switchboard. This panel is fed directly from the mains and the heaters connected to it are always in action. By suitably combining the two sets of switches, it is possible to maintain a very uniform temperature in the testing room. The regulator, which is sensitive to  $1^{\circ}$  F., then comes into action only at fairly long intervals of time. A chart from the recording thermometer, which is located near the centre of the room, is reproduced in Fig. 4.

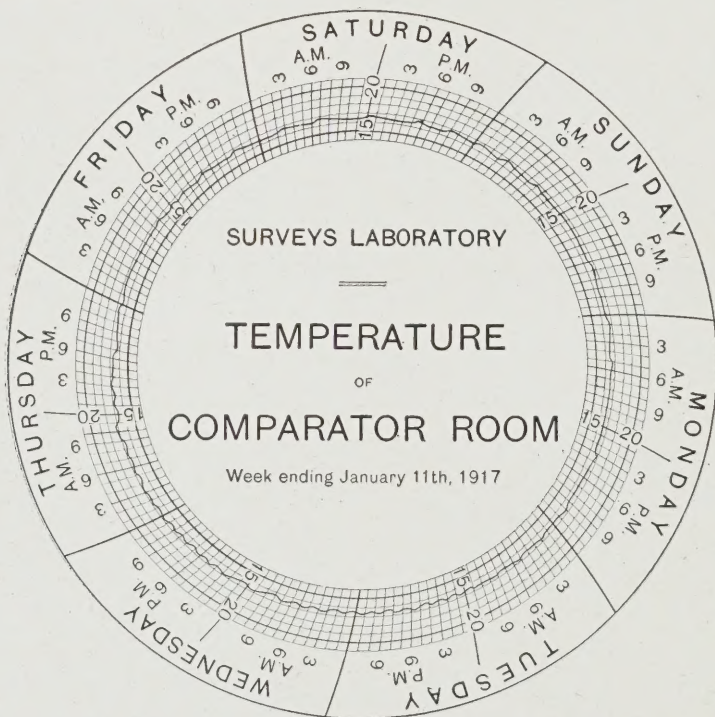


FIG. 4—Temperature Recording Chart

Showing method of recording variation in the temperature of the testing room during the week.

If uniform and close regulation of temperature is desired, it is important that the effect of any local source of heat, other than that of the regular heating system, should be reduced to a minimum. With this end in view, the general illumination is obtained from nitrogen-filled tungsten lamps of low wattage consumption, the light being evenly distributed along the base. The small lights used in connection with the microscopes are supplied from a 6-volt circuit which is fed from a small transformer on the regular lighting circuit.

The Laboratory standard tapes, and other tapes awaiting test, are suspended on special sliding hangers which, when in use, are lowered so that the tapes are within easy reach, but at other times are raised so that the hanging tapes do not interfere with the movements of the workers in the testing room.

## EQUIPMENT

The equipment consists of the following:—

- 1<sup>m</sup> rule (invar).
- 1<sup>m</sup> rule (42 per cent nickel-steel).
- 1<sup>m</sup> rule (nickel).
- 4<sup>m</sup> rule (invar).
- Comparator for comparing 1<sup>m</sup> and 4<sup>m</sup> rules.
- 32<sup>m</sup> comparator base.
- Apparatus for comparing tapes with the base.
- 3-24<sup>m</sup> invar tapes.
- 2-24<sup>m</sup> invar wires.
- Standard steel tapes of various lengths and sections.
- Tape comparator for rapidly comparing tapes with the Laboratory standards.
- Balances for weighing tapes, and various other subsidiary apparatus of a general nature.

The construction of the nickel and the nickel steel metre rules has been delayed by the war, and, subsequently, by difficulties the manufacturers have experienced in obtaining raw materials.\*

## THE INVAR RULES

At present the equipment of the Laboratory includes two invar rules. The first, a 1<sup>m</sup> rule, is used in verifying from time to time the second, a 4<sup>m</sup> rule, employed for standardizing the base. The 1<sup>m</sup> rule is periodically taken for verification to centres in possession of primary standards, which procedure would be impracticable in the case of the 4<sup>m</sup> rule.

The rules were made at the Acieries d'Imphy and finished by the Société Genevoise.

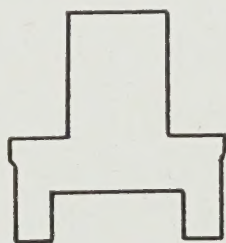


FIG. 5—Section of 1<sup>m</sup> Invar Rule

**One Metre Rule.**

The section of the 1<sup>m</sup> rule is shown in Fig. 5. The rule carries on the outer edges of the exposed neutral surface two sets of graduations, as follows:—

- (1) On one edge, a 1<sup>m</sup> interval graduated throughout in millimetres.
- (2) On the other edge, a 40-inch interval graduated throughout in twentieths of an inch.

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\*The nickel and 42 per cent. rules were finally constructed during 1920, and standardized at the International Bureau early in 1921.

#### Four Metre Rule.

The section of the 4<sup>m</sup> rule is shown in Fig. 6. The rule carries on the outer edge of the exposed neutral surface the following graduations:—

- (1) Five principal divisions at intervals of one metre, numbered consecutively 0 to 4. Each of these principal divisions has an auxiliary division on each side of it at a distance of 1<sup>mm</sup>.
- (2) The metre interval 0–1 is graduated throughout in millimetres.

Both rules were primarily standardized and their coefficients of expansion determined at the International Bureau of Weights and Measures, Paris.

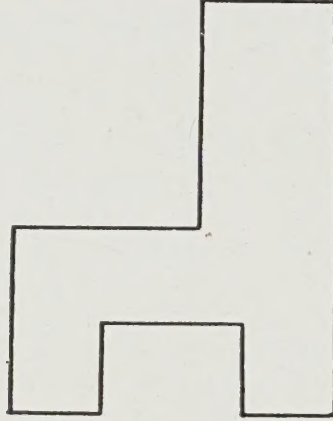


FIG. 6—Section of 4<sup>m</sup> Rule

#### THE ONE METRE COMPARATOR

The standardization of the 4<sup>m</sup> rule by means of the 1<sup>m</sup> invar rule is made on a special comparator at the zero end of the 32<sup>m</sup> base.

By employing rules of the same material and with very small coefficients of thermal expansion, the use of water troughs and other elaborate apparatus is avoided, and comparisons may be made in the air under the temperature control possible in the testing room. It is therefore possible to standardize the 4<sup>m</sup> rule with but a few additions to the apparatus used in the regular tests.

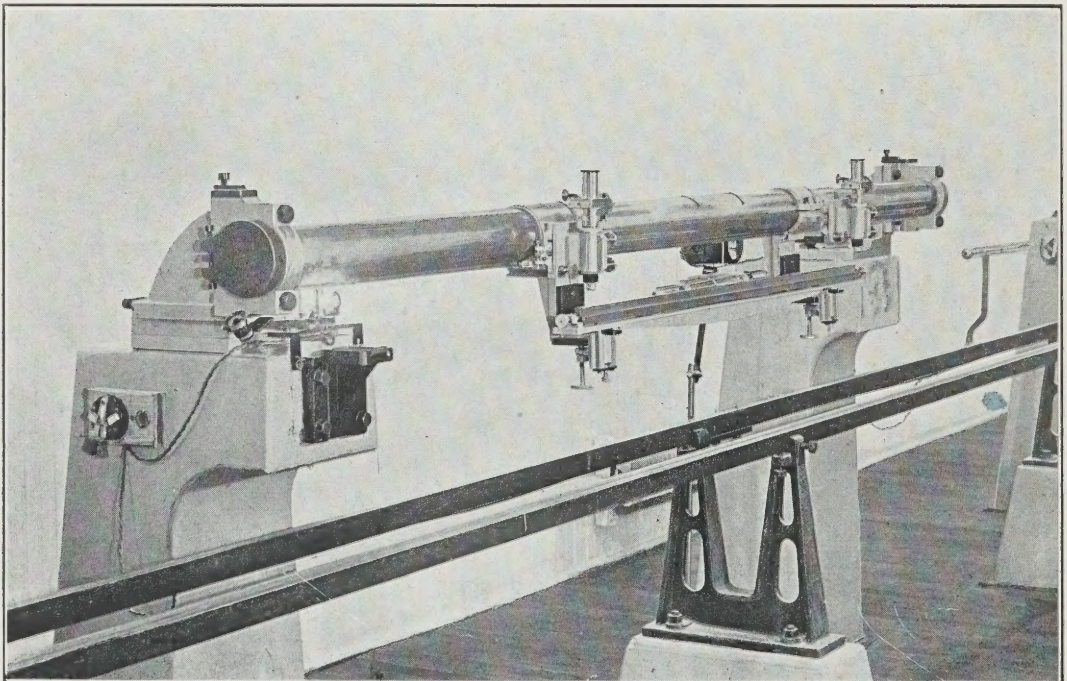


FIG. 7—1<sup>m</sup> Comparator

The general arrangement of the 1<sup>m</sup> comparator is shown in photographic reproduction in Fig. 7, and also in plan and elevation, with the 4<sup>m</sup> rule in position in Figs. 8 and 9.

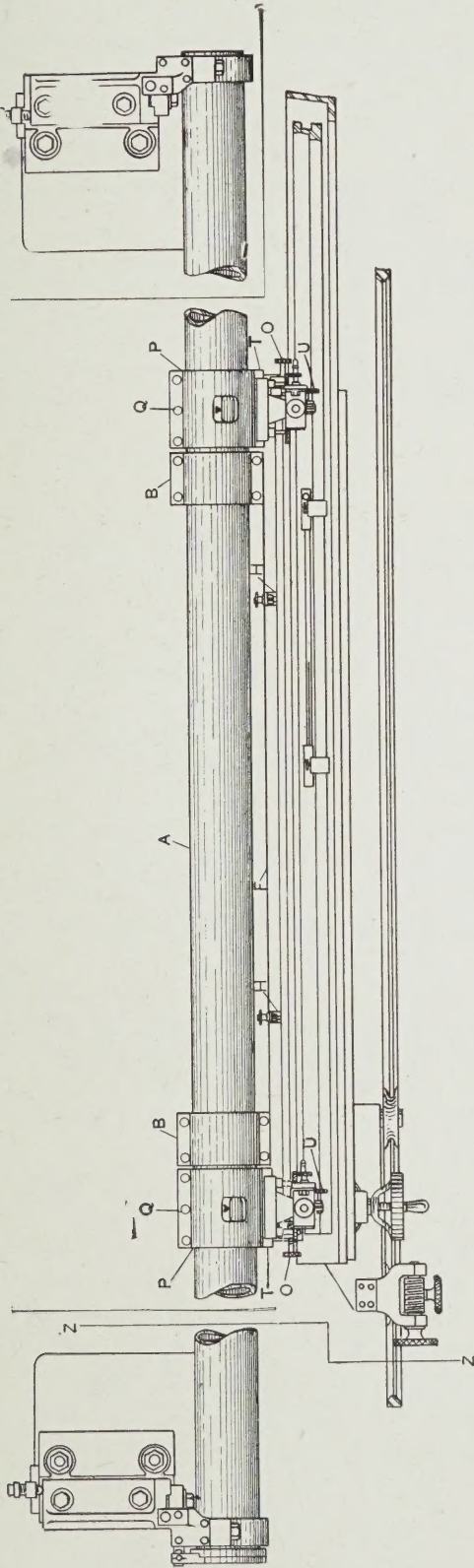


FIG. 8—Plan of 1<sup>m</sup> Comparator

Showing 1<sup>m</sup> invar rule and 4<sup>m</sup> rule carriage in position for standardizing 0<sup>m</sup>-1<sup>m</sup> interval of 4<sup>m</sup> rule.

A—Invar tube, B—Hangers, H—Supports for 1<sup>m</sup> rule, O—Screws giving endwise adjustment to 1<sup>m</sup> rule, P—Microscope brackets, Q—Clamping screws, T—Microscope slides, U—Microscope clamps.

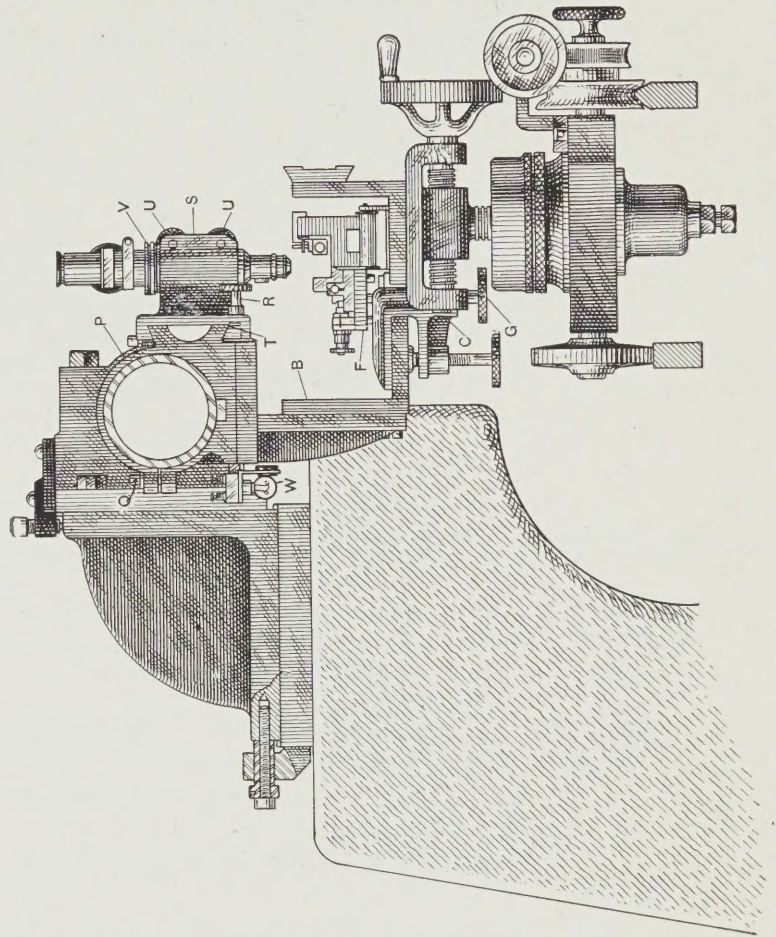


FIG. 9—1<sup>m</sup> Comparator—Section on Z-Z fig. 8

Showing 4<sup>m</sup> rule carriage in position for comparison of 1<sup>m</sup> and 4<sup>m</sup> rules.

C—Clamp supporting 1<sup>m</sup> table, F—1<sup>m</sup> table, G—Screw imparting vertical adjustment to table, R—Microscope holder, S—Microscope holder, V—Focussing nut.

### One Metre Table and Attachments.

The invar tube and supports used in connection with the 32<sup>m</sup> base—a full description of which is given later in the account of the base—are employed to support the necessary extra attachments.

The 1<sup>m</sup> invar rule is suspended from the invar tube by means of two hangers B, Fig. 10. The lower ends of the hangers are suitably shaped to

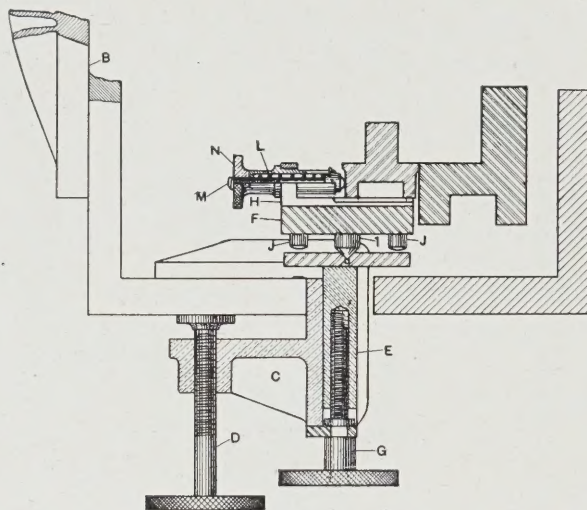


FIG. 10—1<sup>m</sup> Comparator—Sectional end elevation showing detail of support for 1<sup>m</sup> rule  
D—Clamping screw, E—Vertical slide, J—Safety stud, L—Spring, M—Plunger, N—Adjusting nut.

receive special fittings C, which are clamped by the screws D. Each fitting C is provided with a sliding piece E, which enables vertical adjustment to be given to the ends of the table F by means of the finely threaded screw G. The table F is supported at its ends by the usual three point geometrical clamp, from steel plates securely fastened to the upper end of the sliding piece E. At the one end is the conical pointed pin I, resting in a corresponding hole in the plate. The support at the other end of the table is a second conical pointed pin resting in a V groove, together with a round ended screw, which bears on the flat surface of the steel plate. This screw enables the table to be levelled about its longitudinal axis. Two studs J are provided to eliminate any danger of the table being overturned. The table, which is slightly more than one metre in length, carries two curved blocks H, which support the rule at its Airy points. Each block is fitted with a light spring L and an ivory tipped plunger M, used to give lateral adjustment to the rule. The motion of the plunger is controlled by the nut N. Longitudinal adjustment is given to the standard by the ivory tipped screws O, Fig. 8, at the ends of the table F.

The brackets P, Fig. 8, carrying the microscopes, may be clamped by screws Q at any point along the invar tube. These brackets are also adapted to receive the auxiliary benchmarks for use in connection with the base apparatus. In this case, the microscopes, which are not being used, may be easily removed. This is done by unclamping the screws R, Fig. 9, and slipping the microscope holder S from the slides T. The holder S is split vertically and provided with screws U, which clamp the microscope in position after it has been correctly focussed on the rule by means of the focussing nut V.

### Microscopes.

The micrometer microscopes are of the usual type, the objectives having a clear aperture of 5<sup>mm</sup>. The working distance is 30<sup>mm</sup>, giving a magnification of five at the micrometer screw, which has a pitch of 0.5<sup>mm</sup>, hence the value of one turn of the screw is 0.1<sup>mm</sup>. The micrometer drum being divided into one hundred parts, one division corresponds to 0.001<sup>mm</sup>. The eyepiece may

be focussed independently to suit the observer by means of a pin working in an inclined slot in the outer tube. It has a magnification of eight, giving a total magnification of 40 diameters. The divisions on the rule are illuminated by a lamp W, Fig. 9, with diffusing glass, placed behind the invar tube. The rays pass through a recess in the bracket and are brought to a focus at the second principal focus of the objective by means of a lens mounted on the outside of the microscope tube, and an inclined clear glass plate inside.

### THE THIRTY-TWO METRE COMPARATOR BASE

The base consists of a concrete monolith 32<sup>m</sup> long resting on the solid rock. It may be seen in section in Fig. 3. Projecting up through the floor, but isolated from it, are nine concrete piers J, Fig. 11, at intervals of four metres, serving as supports for the permanent benchmarks. There is an additional pier K midway between the 0<sup>m</sup> and 4<sup>m</sup> piers for the purpose of carrying one end of the invar tube apparatus.

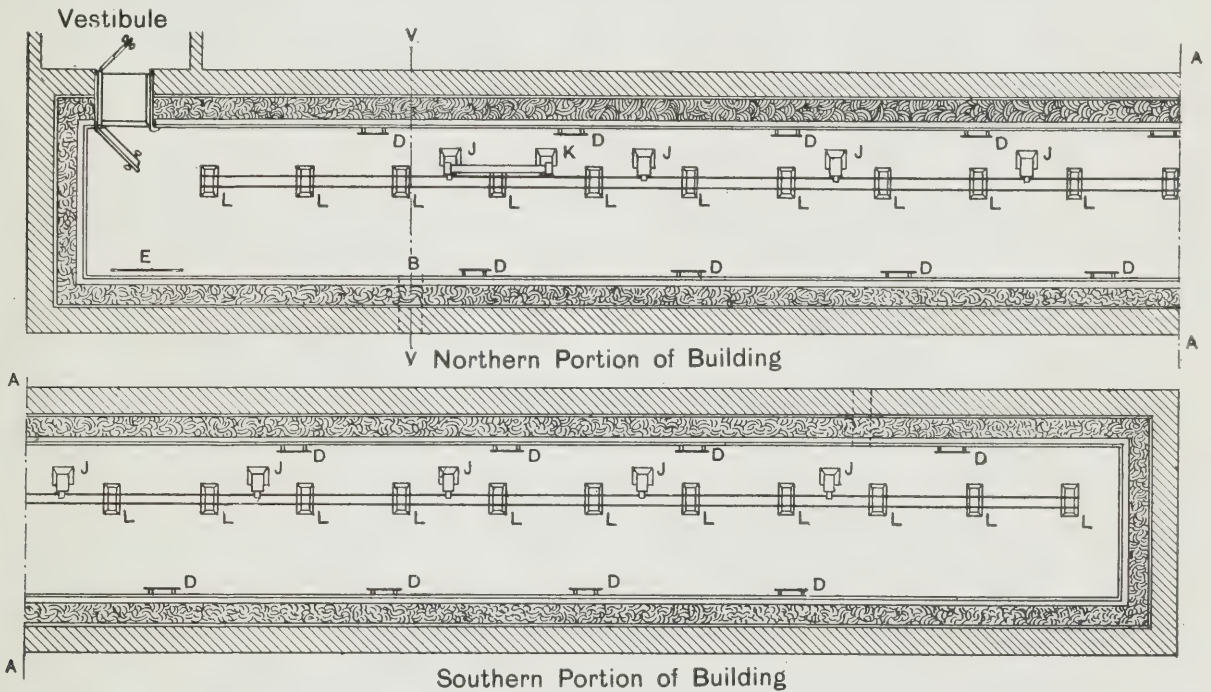


FIG. 11—Sectional Plan of 32<sup>m</sup> Base

Showing location of 32<sup>m</sup> base, track, etc.

B—Air intake, D—Electric heaters, E—Switchboard, J—Benchmark piers, K—Pier supporting end of 1<sup>m</sup> comparator, L—Track piers.

#### Permanent Benchmarks.

The projecting top of each benchmark pier is fitted with a cast iron plate A, Fig. 12, securely fastened to the front of the pier by ordinary foundation bolts. A bracket B fits in the vertical slot planed in this plate, and, when adjusted correctly for height, is clamped by means of a gib and clamping screws. The plate C, bearing the benchmark, slides in a similar horizontal groove in the top of the bracket B, the adjustment and means of clamping for a direction at right angles to the length of the base being also similar. The benchmark graduations are ruled on a small highly polished nickel plate D on the front of the sliding piece C. Each benchmark carries a graduation of six millimetres ruled to tenths of millimetres. The graduations are protected, when not in use, by a slide E, which may be pulled forward to cover them.

After installation the front edges of the benchmark plates were brought into line by the aid of a fine piano wire stretched under tension between the 0<sup>m</sup> and 32<sup>m</sup> benchmarks. A Morin water level was employed to adjust the top surfaces and bring the graduated plates to the same level. No adjustment is provided in a longitudinal direction, and, once the brackets were correctly located for height and alignment, they were permanently clamped.

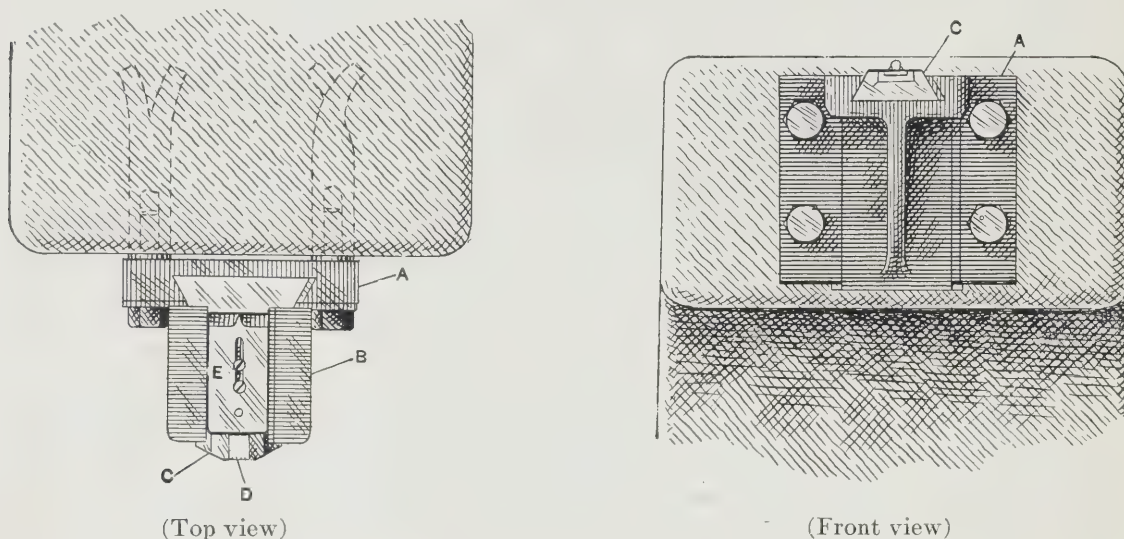


FIG. 12—32<sup>m</sup> Base—Permanent Benchmark Bracket

A—Cast iron plate, B—Bracket, C—Benchmark slide, D—Benchmark, E—Protecting cover.

#### Auxiliary Benchmarks.

When it is desired to standardize a length which is not an exact multiple of 4 metres, the remainder obtained when the length in metres is divided by four, is laid off by utilizing an auxiliary benchmark. This benchmark is supported from the invar tube and may be placed at any point between the 0<sup>m</sup> and 4<sup>m</sup> piers. The tube, which is 2.2 metres in length and 75 millimetres in diameter, is set up in either the 0<sup>m</sup>–2<sup>m</sup>, or the 2<sup>m</sup>–4<sup>m</sup> interval, according to the length being laid off.

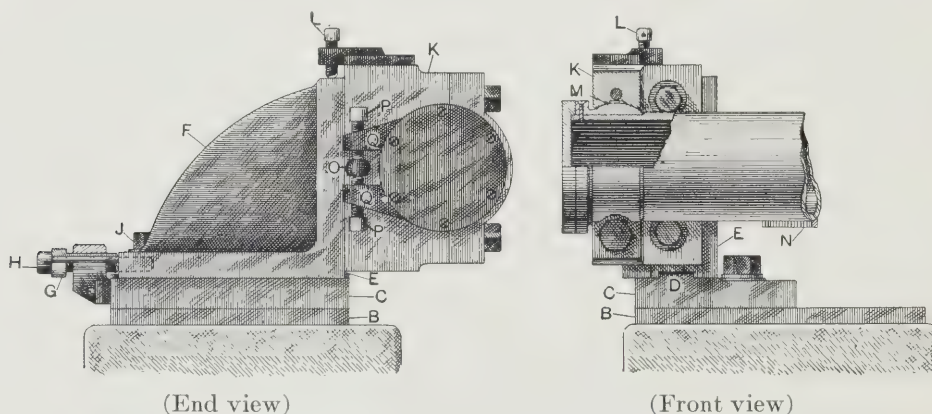


FIG. 13—32<sup>m</sup> Base—Support for End of Invar Tube

B—Steel plate, C—Base plate, D—Projection on base plate, E—Angle plate, F—Stiffening web, G—Horizontal adjusting screw, H—Locking screw, J—Clamping screws, K—Bearing, L—Vertical adjusting screw, M—Spherical collar, N—Key, P, Q—Fittings for adjusting and locking tube.

The end supports, Fig. 13, are bolted to steel plates B on the tops of the piers. The upper surface of each plate is levelled to receive the base plate C of the end support. A projection D planed on the top of this plate engages with a corresponding groove in the angle plate E, which is stiffened by a web F. Horizontal adjustment at right angles to the axis of the tube is given to the angle plate by the screw G in combination with the locking screw H. When correctly adjusted the angle plate may be clamped in position by the screws J. The

vertical face of the angle plate is grooved to receive the bearing K. Vertical adjustment in this case is given to the bearing by the screw L. The bearings K are bored out to a double cone form, giving double line contact to two collars M on the tube, which are turned to be portions of spheres. The invar tube is thus held without restraint, and strains due to temperature changes are obviated by making the tube free to slide in one of the collars. A key N along the bottom of the tube prevents the various fixtures mounted on the tube from rotating while being moved longitudinally. For rotating the invar tube through a small angle during adjustment, and afterwards holding it in position, a lug O is provided on one of the bearings. This engages with two antagonizing screws P, tapped into projections Q, on a plate fastened to the fixed collar of the tube.

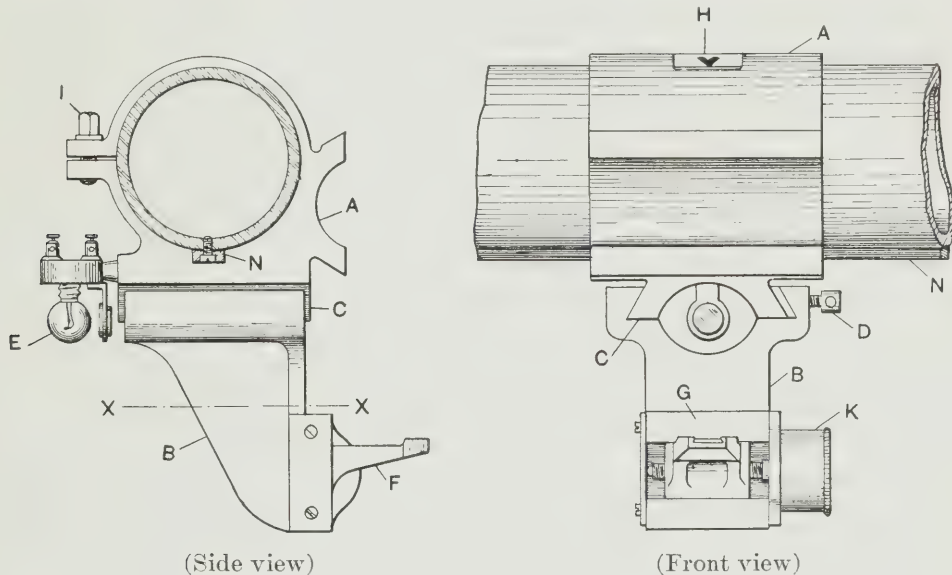


FIG. 14—32<sup>m</sup> Base—Auxiliary Benchmark and Bracket

A—Bracket, B—Hanger, C—Transverse slide, D—Clamping screw, E—Lamp, F—Benchmark bracket, G—Longitudinal slide, H—Index, K—Protecting cap.

The auxiliary benchmark is supported from the bracket A, Fig. 14, by means of the hanger B, which can be easily placed in position on the slide C at the bottom of the bracket A and fastened by the clamping screws D. The benchmark graduations, which are similar to those on the permanent benchmarks, are carried by a small bracket F in the horizontal slides G. An opening and index mark H on the top of the bracket A, together with millimetre graduations on the invar tube carried throughout the entire two metres, enables the bracket to be quickly located in its approximate position, when it may be clamped by the screws I. Final longitudinal adjustment of the benchmark is obtained from the screw J, Fig. 15, actuating the bracket F. When correctly adjusted the head of this screw is protected from further movement by the screwed cap K.

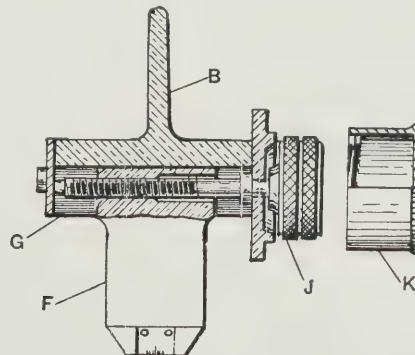


FIG. 15—Section on XX (Fig. 14)—Showing top view of auxiliary benchmark  
J—Longitudinal adjusting screw.

### Rails and Supports.

In front of the benchmark piers is a series of small piers L, Fig. 11, at 2<sup>m</sup> intervals which support the track for the 4<sup>m</sup> rule carriage. This track is carried throughout the entire 32 metres with sufficient extra length to allow the carriage to be run beyond the 0<sup>m</sup> pier while tape comparisons are being made on the base. Special U-shaped brackets Y, Fig. 17, bolted to the piers, are employed to support the rails, which may be adjusted in height by the screws Z and clamped by means of the set screws at the side. The form of these brackets allows the tape under test to sag freely between the rails when supported at the ends only.

### THE FOUR METRE RULE CARRIAGE

The carriage, Fig. 16, consists of a steel beam planed to L-section, stiffened beneath by a truss rod, and supported near each end by a three-wheeled truck.

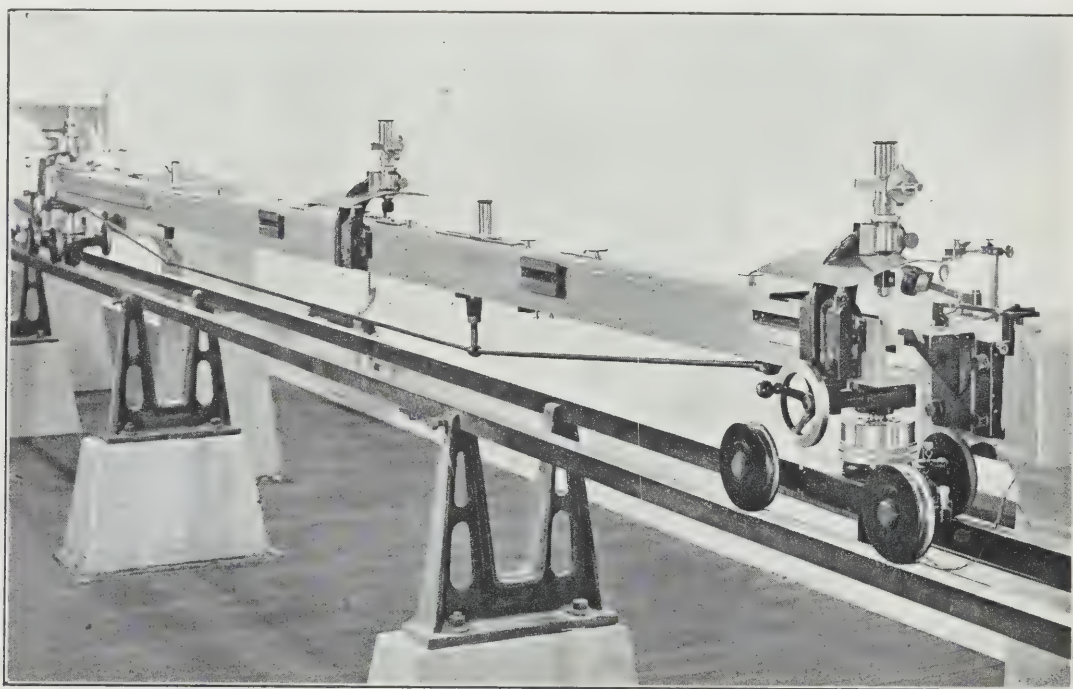


FIG. 16—4<sup>m</sup> Rule Carriage

### Trucks.

Each truck has one slightly barrelled wheel C, Fig. 17, resting on the inner flat rail D, and two others E, with V-grooves to fit the outer rail F. The carriage body is supported from the truck by means of the vertical screw G, the head of which is T-shaped and forms a nut for the horizontal adjusting screw H. The motion of this last screw is controlled by the handwheel I. Vertical adjustment is given to the ends of the carriage by the nut J, resting in a conical hole in the body K of the truck, and operated by the knurled cap L. In order to minimize the friction, and so allow the adjustment to be made readily and without undue effort, the truck is furnished with a spring M inside the cylinder N. The upper end of the spring bears against a piston O, which in turn supports at its centre the washer P. This washer transmits the pressure to the lower end of the nut J. The bottom of the spring rests in a fitting Q, supported on the rounded screw R, which, when the compression on the spring is suitably adjusted, is locked by the nut S.

The carriage is clamped in position, and longitudinal adjustment provided, by a wormwheel T on one of the trucks. This is mounted on a boss forming part of the wheel E, but rotates independently of the wheel until clamped by the knurled nut U. The carriage can then be moved only by means of a worm controlled by the handle V.

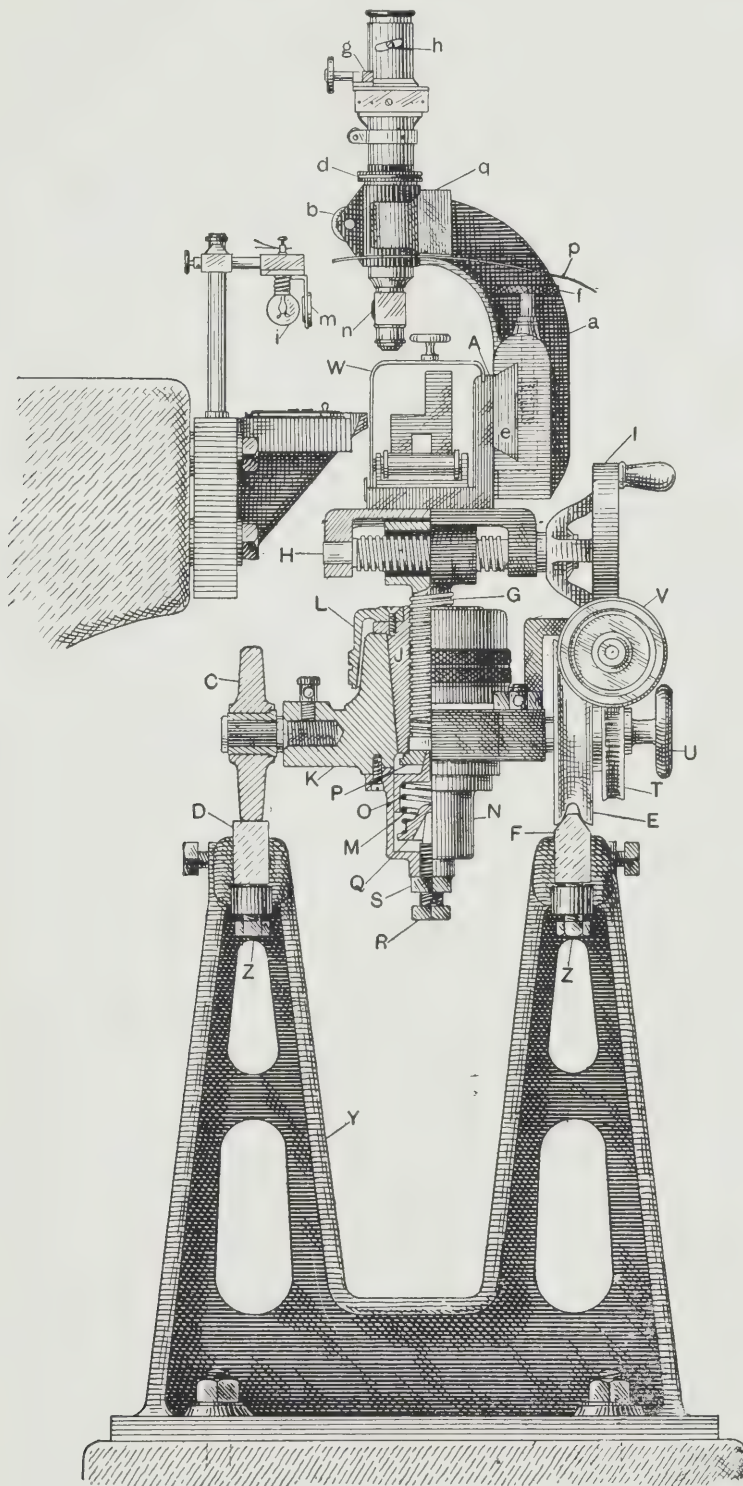


FIG. 17—Sectional Elevation of 4<sup>m</sup> Rule Carriage

C—Inner wheel, D—Flat rail, E—Grooved wheel, F—V rail, G—Vertical screw, H—Horizontal screw, I—Handwheel, J—Conical nut, K—Truck body, L—Handle of conical nut, M—Spring, N—Spring barrel, O—Piston, P—Washer, Q—Adjusting piece, R—Adjusting screw, S—Locknut, T—Wormwheel, U—Locking handle, V—Worm handle, Y—Rail bracket, a—Microscope bracket, b—Clamping screw, d—Focussing nut, e—Slide, f—Clamping screw, g—Eyepiece traversing pinion, h—Focussing stud, i—Lamp, m—Diffuser, n—Window.

### Rule Supports and Casing.

The 4<sup>m</sup> rule rests on two supports placed respectively beneath its Airy points—about 0.88<sup>m</sup> from the ends. One support, Fig. 18, is a roller at right angles to the length of the rule. The second support, Fig. 19, has the axis of its bearings parallel to the longitudinal axis of the rule. It consists of a table

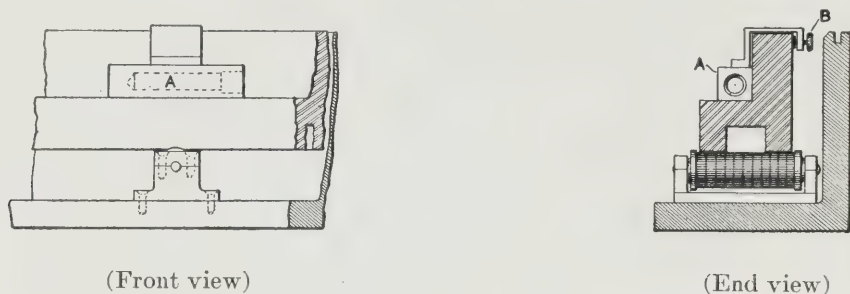


FIG. 18—4<sup>m</sup> Rule—Roller Support  
A—Thermometer holder, B—Clamping screw.

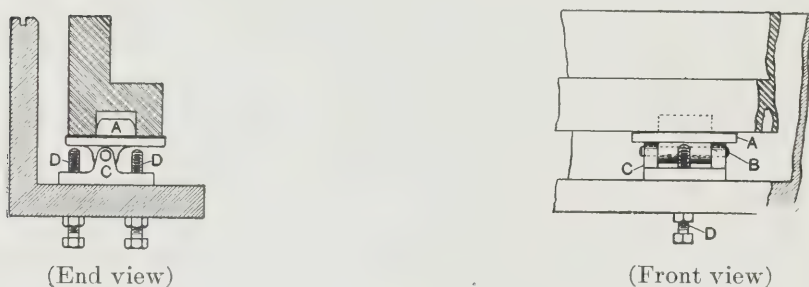


FIG. 19—4<sup>m</sup> Rule—Rocker Support  
A—Table, B—Pin, C—Base, D—Safety screws.

A, carrying the rule, and is fitted with a pin B, the ends of which rest in bearings C. The centre line of the pin is directly beneath the centre of gravity of the section of the rule. The screws D are provided to prevent undue vibration of the support when the carriage is being moved. By the combination of these two supports the rule is entirely free to take its natural shape at any temperature.

The rule is protected by a metal casing W, Fig. 17, arranged in sections that can be easily removed. Small slides in the casing allow the rule to be brought close to the benchmarks during comparison with the pier intervals.

### Thermometers.

Two thermometers of “verre dur,” by Tonnelot of Paris, are used for indicating the temperature of the rule. They are placed beneath glass covered openings in the casing and have their ends resting in aluminium blocks A, Fig. 18, which are clamped to the rule by the screws B. The thermometers are graduated to tenths of a degree centigrade, the length of one degree on the scale being equal to 0.8<sup>cm</sup>. They are read by means of microscopes which are mounted so as to slide in grooves on the top of the cover. The scale corrections of the thermometers, to the international hydrogen scale, were determined at the International Bureau of Weights and Measures, Paris.

### Micrometer Microscope Brackets and Microscopes.

Three micrometer microscopes are included in the equipment of the 4<sup>m</sup> rule carriage. Each microscope is supported in a webbed bracket *a*, Fig. 17. The head of this bracket is bored to be a good sliding fit to the microscope tube and is split vertically so that the halves may be clamped together by the screw *b*. A finely threaded nut *d*, bearing on the top of the

bracket *a*, enables the microscope to be correctly focussed on the rule. The microscope bracket is fitted to the slide *e*, screwed to the back of the carriage body. It may be clamped, when correctly located, by the screws *f*. There are four slides, one, slightly more than one metre in length, enables a microscope to be placed in position opposite any part of the first metre interval on the rule, this interval, as previously mentioned, being graduated throughout in millimetres. The remaining slides are only slightly longer than the width of the microscope brackets and are located at the 2<sup>m</sup>, 3<sup>m</sup> and 4<sup>m</sup> points of the rule. It is found more convenient in working to allow two of the microscopes to remain permanently as far as possible at the 0<sup>m</sup> and 4<sup>m</sup> graduations respectively, for use in standardizing the 4<sup>m</sup> intervals on the base. The third microscope is used at intermediate points on the rule when some portion of the four metres is needed in setting the auxiliary benchmark. It is necessary to move one of the end microscopes only when either the 2<sup>m</sup> or the 3<sup>m</sup> graduation is being used in conjunction with part of the first metre.

Each microscope has an objective with a clear aperture of 6.5<sup>mm</sup> and a working distance of 42<sup>mm</sup>, the total magnification being 20 diameters. The micrometer screw has a pitch of 0.3<sup>mm</sup>, and the magnification of the objective being three times, the value of one turn of the screw is equivalent to 0.1<sup>mm</sup>. One of the one hundred divisions into which the drum is divided corresponds to 0.001<sup>mm</sup>. A rack and pinion motion *g* carries the eyepiece over any portion of the field, in which forty whole turns of the screw can be counted on a comb. Each observer can adjust the eyepiece to his vision by slightly rotating it, when it is raised or lowered by a pin working in an inclined slot *h*.

A lamp *i*, on the benchmark support, illuminates the graduation beneath the objective. The light after passing through a diffusing glass *m*, placed just before the lamp, is brought to a focus by a lens *n* in the front of the microscope tube. An inclined piece of clear glass within the tube reflects the rays vertically downwards through the objective, the system causing them to emerge parallel.

The breath-shields *p* protect the rule and benchmarks from the breath of the observers while using the microscopes. They are fastened by spring clips *q* to the brackets *a*.

## APPARATUS FOR COMPARING TAPES WITH THE BASE

When comparing tapes with the base the 4<sup>m</sup> rule carriage is moved beyond the end pier. Tapes may be tested either when suspended from the ends only, or when carried at intervals on supporting pulleys. In the former case the U-shape of the rail-supporting brackets permits any tape under ordinary tension to hang in a single catenary. No attempt is made to determine directly the length on the flat, owing to the excessive friction that would be involved. In this case the tape is compared while supported at close intervals on the pulleys, and the small sag correction is calculated and applied to the observed length.

### Fixed End Support.

At the zero end, Fig. 20, the tape is fastened to a special supporting stand by means of a swivel joint. The base A of the stand is clamped to the rails by a strap B with hinged bolts and wing nuts C. A nut D, fitted to the top of the boss on the base A, imparts vertical adjustment to a screw E, and through it to the upper portion of the support. The screw E, which is of ample strength, is square threaded and prevented from rotating by a key. There is a transverse slide securely fastened to the top of the screw E upon which the base of the

sliding head F is fitted. Transverse adjustment is imparted to the head by a screw G. The end of the tape is attached to a horizontal screw H passing through the head F, and which is adjusted, in the direction of the length of the tape, by a knurled nut I.

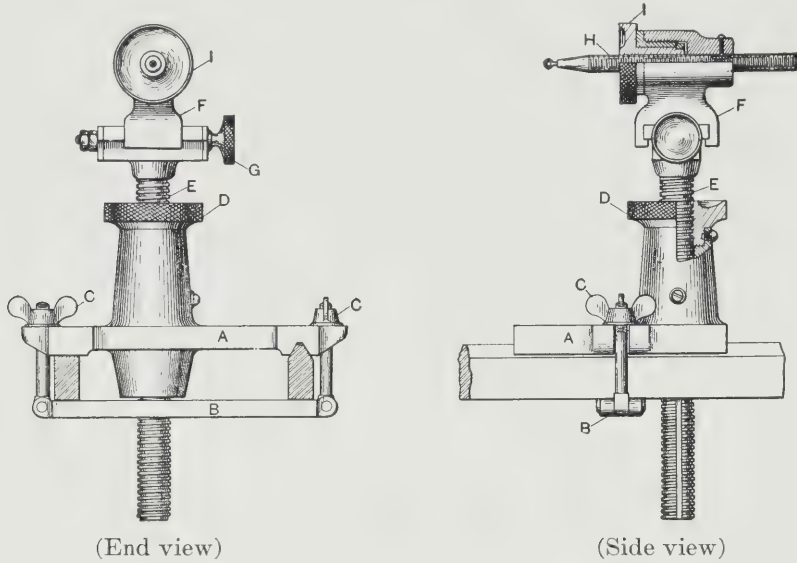


Fig. 20—32<sup>m</sup> Base—Fixed End Support for Tapes

A—Base, B—Clamp strap, C—Wing-nut, D—Vertical adjusting nut, E—Vertical screw, F—Transverse sliding head, G—Transverse adjusting screw, H—Longitudinal adjusting screw, I—Longitudinal adjusting nut.

#### Tension End Pulley Support.

At the other end tension is imparted to the tape by a weight, connected to it by a fine piano wire and swivel hook. The wire passes over a special V-grooved steel pulley A, Fig. 21, 300<sup>mm</sup> in diameter and designed for maximum lightness consistent with the necessary strength. It is mounted on a stiff frame B, supported in turn from a base C bolted to the rails in a similar manner to the fixed end support. In order to reduce friction to a minimum, the wheel, besides being as light as possible, is mounted on ball bearings, with balls 3<sup>mm</sup> in diameter. The spindle D, threaded throughout its length, is supported at its ends by nuts forming part of the frame. This construction provides transverse adjustment

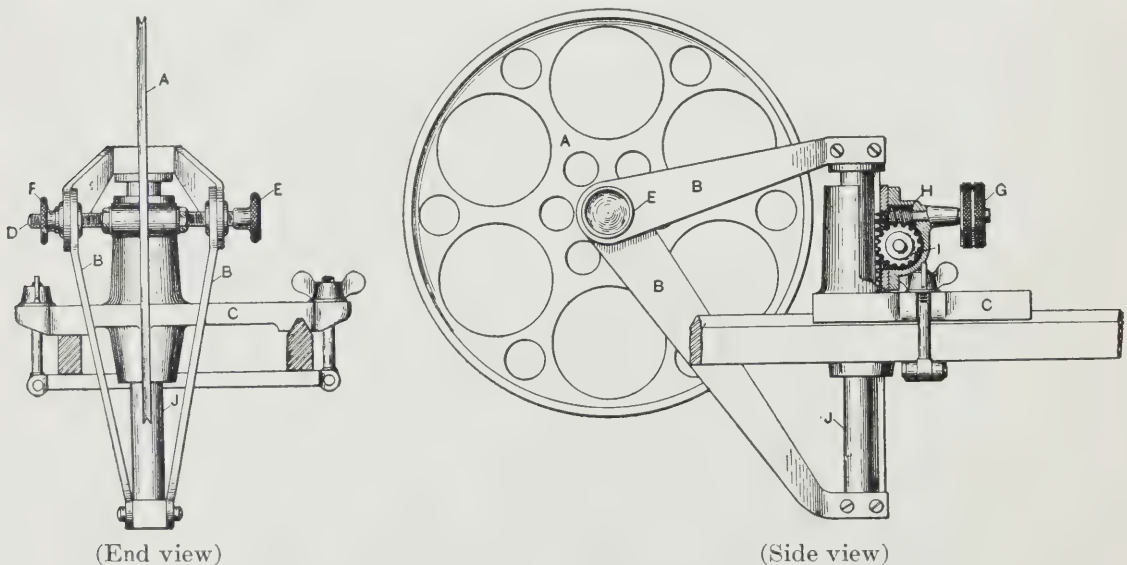


Fig. 21—32<sup>m</sup> Base—Tension Pulley and Support

A—Pulley, B—Frame, C—Base, D—Spindle, E—Handle, F—Locknut, G—Vertical adjusting handle, H—Worm, I—Wormwheel, J—Vertical rod.

for the wheel by rotating the handle E keyed to the spindle. When necessary the spindle can be locked in position by the nut F. The pulley is adjusted to the correct height by the handle G, mounted on a shaft carrying a worm H. A wormwheel I, engaging with this worm, is geared directly to a helical rack on the sliding rod J.

### Intermediate Pulley Supports.

When the length of a standard tape is required on the flat it is usually compared with the base while supported at 4<sup>m</sup> intervals. When supported at such small intervals the sag correction to be applied, in order to reduce the observed length to that of the tape when perfectly straight between its end graduations, is very small, and the possible error in the correction is well within the limits of accuracy required in the determination.

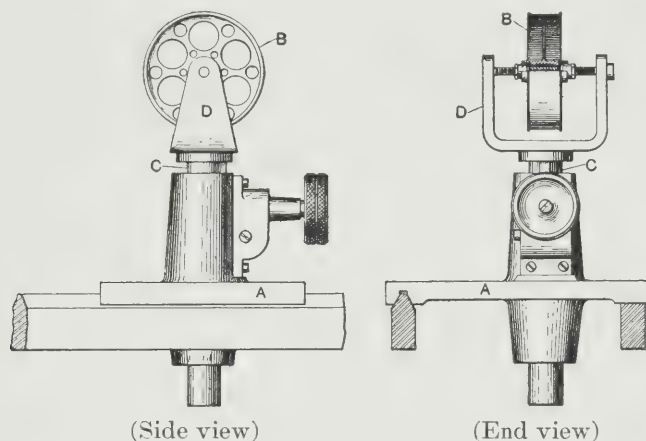


FIG. 22—32<sup>m</sup> Base—Intermediate Pulley Support for Tapes  
A—Base, B—Pulley, C—Rod, D—Forked bracket.

Special pulleys, one of which is shown in Fig. 22, are used to support the tape at the desired intervals. The base A for this pulley is somewhat similar to that carrying the large tension pulley, with the exception that it is not necessary to make any provision for clamping it to the rails. The adjustment for bringing the pulley B to the correct height is also similar. The vertical sliding rod C carries at its upper end a forked bracket D forming a support for the ends of the pulley spindle. Advantage was taken of the fact that these pulleys were under practically no strain, to construct them as light as possible. They are 90<sup>mm</sup> in diameter and are made of aluminium alloy, machined all over and carefully balanced. They weigh only 55 gms. each, and the greater portion of this weight is concentrated in the hub, the web and rim being made extremely thin. The ball bearings are of excellent workmanship and highly finished. The diameter of the cups is 12.5<sup>mm</sup> with balls of 1.5<sup>mm</sup> diameter.

### Thermometers and Supports.

The temperature of the tape is indicated by a series of precise thermometers arranged in supports along the track, one being placed in the centre of each pier interval. The supporting cages, Fig. 23, which hold the thermometers parallel to, and at a short distance from the tape, are designed to afford ample protection to the thermometers. A small bearing A, fastened to the back of the inner rail, forms a socket for the cranked rod B. The offset of this rod enables the trucks of the 4<sup>m</sup> rule carriage to pass without interference, after the support has been turned away from the track through an angle of 180°. A screw C clamps the rod in either position. The cage carrying the thermometer is fastened to the rod B by a U-piece D and clamping screw E. Two brackets F and G, on the plate H, form supports for the wire protecting cage I. The ends of the wire loops forming this cage are soldered into the head J. The thermometer is inserted through a hole in this head and when in position is held by a pin K, passing

through the eye formed at the upper end of the stem. The second support, near the bulb end, is the bracket F. The supporting cage is polished and a reflector L is provided to shield the bulb, when necessary, against possible radiations from external sources.

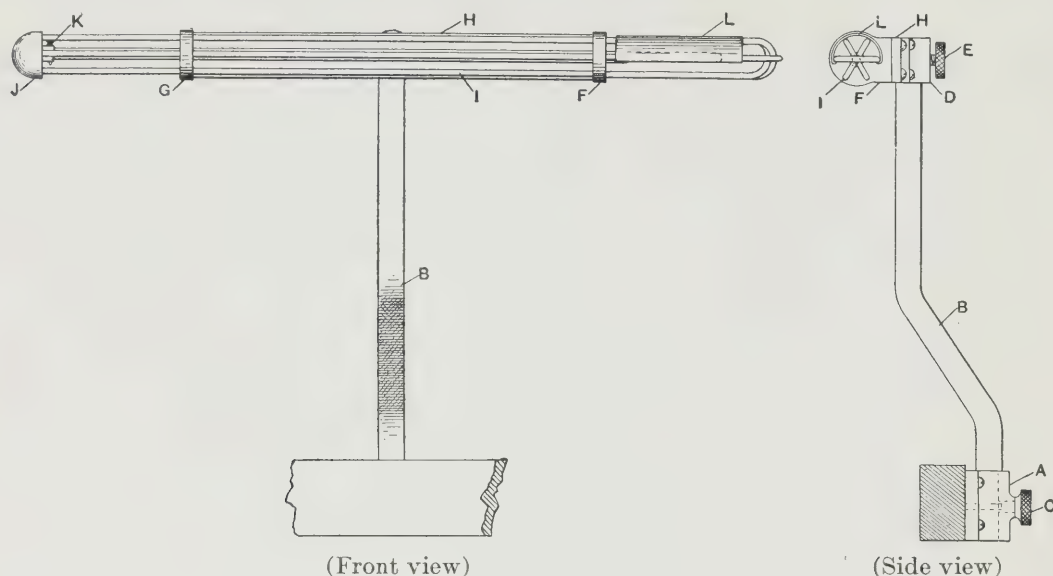


FIG. 23—32<sup>m</sup> Base—Thermometer Stand

A—Bearing, B—Rod, C—Lower clamping screw, D—U-piece, E—Upper clamping screw, F, G—Cage supports, H—Back plate, I—Wire cage, J—Head, K—Safety pin, L—Reflector.

The thermometers used during tape comparisons are exactly similar to those described in connection with the 4<sup>m</sup> rule carriage. They have been standardized to the international hydrogen scale of temperature, and their ice points are carefully redetermined, from time to time, with the aid of the thermometer testing apparatus at the Surveys Laboratory. Two small thermometers, placed in light metal boxes laid directly on the tape, over supporting pulleys, may also be used in conjunction with the thermometers on the track.

#### Reading Apparatus.

The benchmark graduations being spaced at intervals of only 0.1<sup>mm</sup>, it is possible to compare standard tapes with the base to a sufficient degree of accuracy without recourse to micrometer microscopes. With the fine graduations on the standard tapes it is quite easy to estimate the interval between adjacent rulings on the tape and benchmark with the aid of a small reading microscope, this interval never being greater than 0.05<sup>mm</sup> (50 microns).

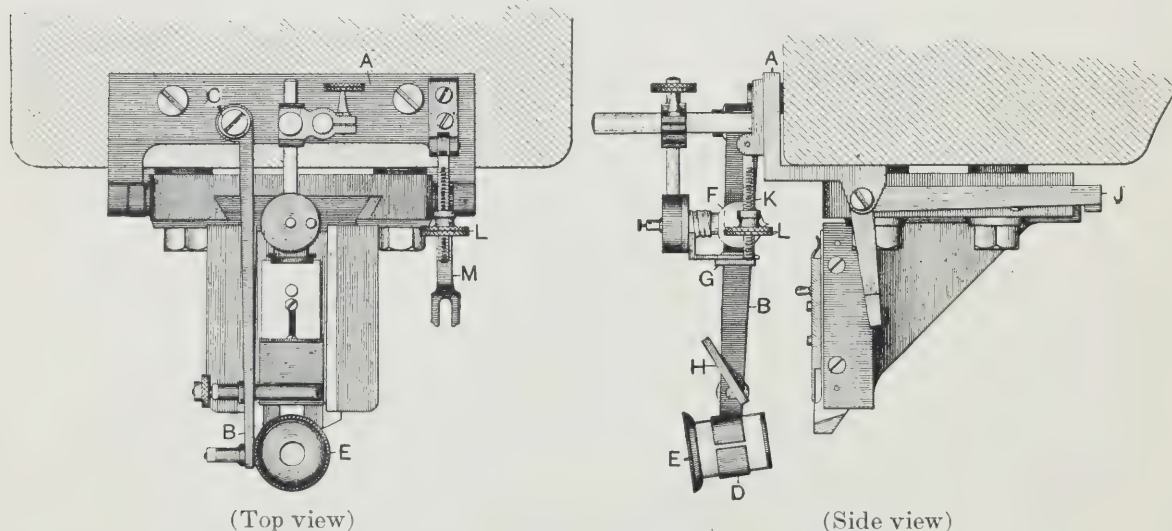


FIG. 24—32<sup>m</sup> Base—Reading Microscope and Attachments

B—Adjustable arm, E—Reading microscope, F—Lamp, G—Diffuser, H—Mirror, J—Tape support.

The apparatus employed for the comparisons is shown in Fig. 24. A casting A, fastened to the top of the pier, bears an adjustable arm B, which swings in the horizontal plane about the screw C. The reading microscope E is held in the clip D, which is pivoted so that the line of sight may be suitably adjusted; it has a magnification of five diameters, and is focussed by pushing through the clip D, which holds it by friction. The graduations are illuminated by a small lamp F behind the ground glass G, a mirror H reflecting the rays at a suitable angle. A bracket J is also provided for holding the tape during comparison at the same level as the benchmark, when required. Adjustment is given by the swivel bolt K and nut L. When not in use the bracket is released by lifting the bolt K out of the slot in the arm M, when the bracket swings down and hangs vertically.

### Friction in the Apparatus.

It has been mentioned that by spacing the supporting pulleys at comparatively small intervals, it was possible to compute the length of a tape on the flat by applying a small correction to the measured length. In comparing tapes in this way, it is important that friction in the several supports shall not introduce an error of such magnitude as would affect the precision of the final results. It is of interest, therefore, to investigate the amount of friction in the apparatus and its effect on the tape comparisons. When the apparatus was installed a careful determination was made of the amount of friction expressed as a force in the line of tension at the periphery of the pulleys. The magnitude of this force was found by winding a silken thread around each supporting pulley, in turn, and adding weights until the pulley commenced to revolve with no apparent acceleration. This was done for several positions and in both directions of rotation. In the case of the tension pulley the wire used in tape tests was employed, weights being attached to the ends of this, in order that the amount of friction might be found under working conditions. A summary of these results is shown in Table I.

TABLE I

Amount of friction expressed as alteration of tension in line of tape.

Tension Weight	Friction	
	Tension Pulley	Tension pulley + 7 supporting pulleys
10 lbs.	2.26 grms.	2.92 grms.
10 Kgms.	3.75 "	4.41 "

It will be noticed that the main portion of the friction is in the tension pulley, and that very little is introduced by the supporting pulleys. This is what would be expected from the design of these pulleys and the small load carried by them. As one result of the small amount of friction in this apparatus it was necessary to provide a fixed support for one end of the tape, experience having shown that with a pulley and tension weight at both ends it was impossible to keep the tape steady during comparisons.

While it is gratifying to know that the friction is so small, it is of further interest to determine its effect upon the tape comparisons.

It is shown in text books on surveying that the horizontal length between the extremities of a tape stretched under tension, and supported in n equal spans, is:—

$$L_1=L_0-\frac{W^2L_0^3}{24\,P^2n^2}+\frac{P\,L_0}{A\,E}\dots\dots\dots(1)$$

Where  $L_0$ =Length of tape on the flat, under no tension.  
 $W$ =Weight of tape per unit of length.  
 $P$ =Applied tension.  
 $A$ =Cross-sectional area of tape.  
 $E$ =Modulus of elasticity.

If the friction is considered as causing an uncertainty of amount  $\delta P$  in the value of  $P$ , the observed length of the tape,  $L$ , may lie anywhere between:—

$$L_2=L_0-\frac{W^2\,L_0^3}{24(P+\delta P)^2n^2}+\frac{(P+\delta P)L_0}{A\,E}\dots\dots\dots(2)$$

and

$$L_3=L_0-\frac{W^2\,L_0^3}{24(P-\delta P)^2n^2}+\frac{(P-\delta P)L_0}{A\,E}\dots\dots\dots(3)$$

The total range, or difference between these two lengths is, neglecting quantities of the second order:—

$$L_2-L_3=\frac{W^2\,L_0^3}{24\,P^2}\times\frac{4\delta P}{n^2P}+\frac{2L_0\delta P}{A\,E}\dots\dots\dots(4)$$

The first term is the effect upon the shortening due to sag, while the second is the effect upon the elastic lengthening. While the second is independent of the number of supports, the effect upon the shortening due to sag, for the same amount of friction, varies inversely as the square of the number of spans.

In order to verify experimentally the above formula (4) for the effect of friction upon the observed length of a tape, some tests were made with the apparatus, using tapes of 66 feet and 100 feet in length. The tapes were compared with the base in the usual way, but settings were made first from right to left (allowing the weight to fall) when the tension may be taken without serious error as the difference between the tension weight and the friction; and second, from left to right (raising the weight) when the effective tension may be taken as the sum of the tension weight and the friction. It can be seen that the difference between the length determined in these two ways should be that given by the expression (4). The same pulleys and tension weights were used as in the experiments of which the results are given in Table I. Table II shows the mean of several determinations, together with the calculated values (using the results given in Table I) of the differences in length. Considering the small quantities involved and the variation to be expected in the actual amount of the friction the agreement is remarkable.

TABLE II

Values of the range in the observed lengths of tapes due to friction in the apparatus:—

P	L=66 Ft.				L=100 Ft.			
	n=8		n=1		n=8		n=1	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
10 lbs. 10 Kgms.	4μ 5	8μ 5	9μ 6	13μ 3	6μ 8	11μ 12	28μ 11	21μ 12

## THE TAPE COMPARATOR

Previous to the installation of the comparator base, all measures tested by the Surveys Laboratory were compared with steel or invar standard tapes. It was necessary to have these standards verified, from time to time, at the National Physical Laboratory or other metrological laboratories. Comparisons of measures with the standard tapes were made on a tape comparator, which is now located along the wall of the main testing room and used mainly for the testing of steel tapes.

The principle of the tape comparator, which was originally proposed by Dr. Deville, the Surveyor General, is somewhat similar to that of the apparatus for comparing standard tapes with the base. In the former, the Laboratory standard tape supported on a series of pulleys, takes the place of the base interval in the latter. The two tapes are supported independently, side by side, on a series of double pulleys. The zero ends are attached to fixed brackets, while tension is imparted at the other end of the comparator through the medium of weights and tension pulleys, the comparisons being made by means of travelling microscopes.

### Fixed End Supports.

The zero or fixed end of the tape comparator is shown in Fig. 25. One end of the standard tape—which will be called the “standard,” to distinguish it from the tape being compared, referred to as the “tape”—is attached by a swivel hook and wire to a sliding block A in the bracket B. The bracket is correctly located for height, and transverse adjustment is given to the standard by the screw C tapped into the block A. The corresponding end of the tape is fastened to the slide D in the bracket E. Longitudinal adjustment is obtained by the screw F, to which is keyed the gear G in mesh with a similar gear H, on

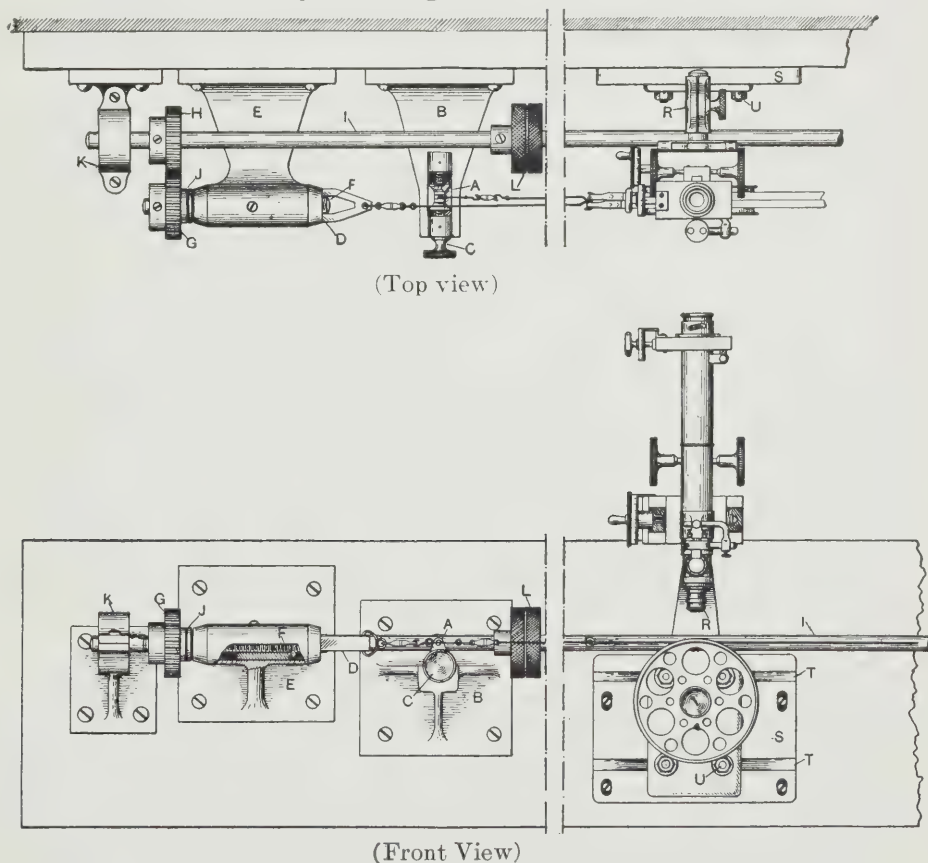


Fig. 25—Tape Comparator—Showing fixed ends of tapes in position for comparison.

A—Slide with transverse adjustment, B—Bracket for support A, C—Transverse adjusting screw, D—Slide with longitudinal adjustment, E—Bracket for slide D, F—Longitudinal adjusting screw, G, H—Gears, J—Thrust bearing, K—Rod bearing, L—Handle.

the rod I. End thrust is taken by the ball thrust bearing J. The rod I is carried throughout the entire length of the apparatus in ball shaft bearings K. At suitable intervals knurled handles L are keyed to the rod, which latter enables the tape to be moved relative to the standard from any point along the comparator.

#### Tension End.

The tension weights and pulleys are similar to those in use on the base. Two steel pulleys O, Fig. 26, are mounted on spindles with ball bearings, the spindles being screwed into brackets P until the pulleys are correctly in line with the tape or standard. Knurled handles Q are keyed on the spindles for the purpose of making this adjustment.

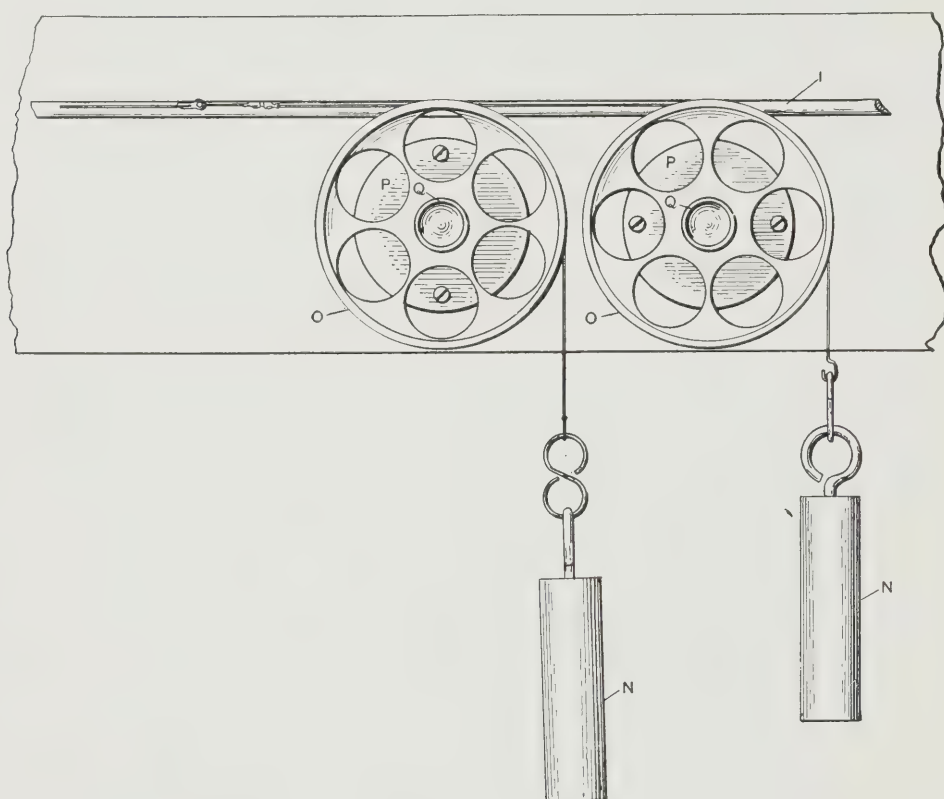


FIG. 26—Tape Comparator—Tension Weights and Pulleys

I—Longitudinal adjusting rod, N—Tension weights, O—Pulleys, P—Brackets, Q—Transverse adjusting screws.

#### Intermediate Supporting Pulleys.

In this apparatus the supporting pulleys are mounted in pairs side by side; one of each pair being used respectively for the tape and the standard. They are of the same construction as those used on the base apparatus, the supporting spindles being screwed into hubs which can be quickly inserted into brackets arranged at suitable intervals along the comparator.

#### Microscopes and Microscope Brackets.

In the case of the tape comparator, measures having widely differing kinds of graduation are encountered, so that in many cases it would be impossible to obtain accurate results by estimating the interval between the tape and standard in the same way that comparisons are made on the base apparatus. The settings and measurements are made with the aid of two low power microscopes fitted to horizontal slides and moved by means of micrometer screws. One turn of the screws is equal to  $1^{\text{mm}}$  and the micrometer drums are graduated to  $0.01^{\text{mm}}$ .

The tapes are illuminated by means of a small lamp outside the microscope tube; the rays, which pass through a ground glass diffuser, are reflected down through the objective by a prism placed within the tube, opposite to an opening.

The microscopes are clamped in brackets R, Fig. 25. These brackets have supporting pulleys beneath the microscopes to ensure that the two tapes being compared are at the same level. One pulley only is used at the fixed end, while the bracket at the other end has two, similar to those on the intermediate supports. A limited amount of longitudinal adjustment is provided by mounting the bracket on a plate S. The dove-tailed slots T, in this plate, are fitted with slides and studs, which enable the bracket R to be clamped in position by the nuts U, after it has been correctly located.

#### **Friction in the Tape Comparator.**

Friction tests made on this apparatus, similar to those mentioned in connection with the base, showed the friction to be very small and of about the same value as in the base apparatus for an equal number of pulleys.

### **STANDARDIZATION OF THE FOUR METRE RULE**

The 4<sup>m</sup> rule is at present standardized by comparing it, metre by metre, with the 1<sup>m</sup> invar rule, or, in case of subdivisions of a metre, by comparing the interval on the 4<sup>m</sup> rule with the corresponding interval on the 1<sup>m</sup> rule.

On the day previous to the standardization, all the ventilators in the building are closed and the blower fans set running to circulate the air. The 1<sup>m</sup> rule is placed in position on the supporting table F, Fig. 9, and the 4<sup>m</sup> rule, in its carriage, placed opposite the 1<sup>m</sup> comparator. The two rules are then allowed to remain in this position for 24 hours in order that they may attain the same temperature as that of the room. In making a comparison the two microscopes are first carefully focussed on the surface of the 1<sup>m</sup> rule bearing the graduations. Correct adjustment of the rule relative to the microscopes is made by the means explained in connection with the description of the apparatus. The 4<sup>m</sup> carriage is then clamped in position with the first metre interval of the rule opposite the 1<sup>m</sup> rule. Having adjusted the 4<sup>m</sup> rule to the correct height, it is brought very close to the edge of the 1<sup>m</sup> rule by the transverse adjusting screws on the carriage. The value of one turn of each of the micrometer screws is determined at the commencement of the standardization and again when it is completed. The actual micrometer measurements for the comparisons are made simultaneously by two observers, ten sets of readings being taken, the observers changing places at the completion of the first five. The thermometers indicating the temperature of the rules are read between the two half sets. This programme is repeated for each of the four 1<sup>m</sup> intervals and the rules are again compared, working in the opposite direction.

#### **Curvature of the Four Metre Rule.**

Owing to the natural flexure, and a slight curvature in the horizontal plane, of the 4<sup>m</sup> rule it is necessary to apply a small correction to the sum of the four 1<sup>m</sup> intervals measured, to reduce them to their projection on the line, joining the ends of the 0<sup>m</sup> and 4<sup>m</sup> graduations. The relative inclination of the four 1<sup>m</sup> chords was obtained by rigidly mounting a collimator on the 4<sup>m</sup> rule carriage, the cross-wires being illuminated by a small 4 C.P. lamp. A second collimator, fitted with a micrometer screw and eyepiece, was firmly mounted on the rails, over the end supporting pier. The two auxiliary benchmarks were then placed 1<sup>m</sup> apart on the invar tube.

The diagram Fig. 27, illustrates the method followed, AB representing the rule and H the collimator. This is shown attached to the rule in order to simplify the diagram; actually, as the rule does not move relatively to the carriage during this experiment, they may be regarded as one and the same. The track collimator is indicated by K.



Fig. 27



Fig. 28

Diagrams Showing Method of Determining Curvature of 4<sup>m</sup> Rule

A, B—4<sup>m</sup> rule, F, G—Adjustable benchmarks, H—Collimator attached to 4<sup>m</sup> rule carriage, K—Collimator fixed to track

The rule was first placed with the 0<sup>m</sup> and 1<sup>m</sup> graduations, A and C, opposite the auxiliary benchmarks, F. and G., and adjusted to be at the same level as the benchmark plates at these points. In the horizontal determinations great care was taken to ensure that the 0<sup>m</sup> and 1<sup>m</sup> points on the rule were at equal distances in front of the two benchmarks. This latter adjustment was checked by measuring the actual spacing with the microscopes. When the rule had been thus adjusted, a reading was taken by means of the micrometer of the collimator K on the track. The carriage was then moved until the rule occupied the position A' B', Fig. 28. Having adjusted it as before, so that the 1<sup>m</sup> and 2<sup>m</sup> graduations, C' and D' were in the correct position relative to the benchmarks, the carriage collimator occupied the position H'. A second reading was then taken by means of the fixed collimator. The readings so obtained gave the inclination of the line of collimation X X, of the collimator H, in the first position, and X' X' in the second, to the zero line O O of the collimator K. The difference between these two readings, it will at once be seen from an inspection of the diagrams, gave the angle between the lines of collimation in the two positions, or the angle between the chords A C and C D.

This procedure was repeated for each metre interval from zero to four metres and again in the reverse direction.

In measuring the curvature in the vertical plane, the collimator on the track was rotated to bring the micrometer screw vertical. The rule was then adjusted to the auxiliary benchmarks as before, special care being taken in this portion of the determinations, to ensure that the ends of the intervals were exactly at the same level as the benchmark plates. The procedure in other respects was exactly similar to that in the determination in the horizontal plane.

The distance of the edge of the rule at the 1<sup>m</sup>, 2<sup>m</sup> and 3<sup>m</sup> graduations from the line joining the edge at the 0<sup>m</sup> and 4<sup>m</sup> points was then easily obtained, and the necessary corrections computed. The total correction was small, amounting to less than one part in a million.

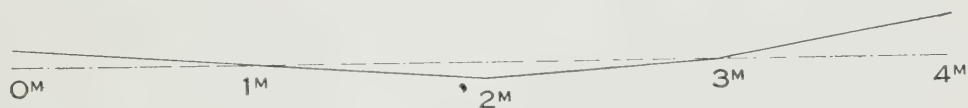


FIG. 29—Plan of 4<sup>m</sup> Invar Rule

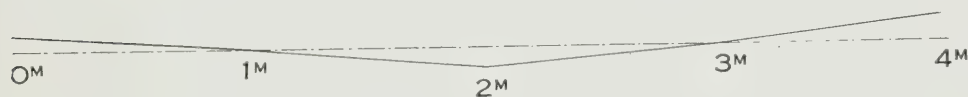


FIG. 30—Elevation of 4<sup>m</sup> Invar Rule

Figs. 29 and 30 represent in plan and elevation the relative inclinations of the four 1<sup>m</sup> chords of the curve assumed by the rule, the proportion of the scales being such that the deflection from a straight line is magnified one hundred times.

## MEASUREMENT OF THE BASE

The measurement of the base is usually made in conjunction with the verification of standard tapes. The procedure in such verifications is, measurement of base, comparison of standard tapes and finally a second measurement of the base. In a base of the permanent benchmark type constructed like the one under consideration, the spacing of the pier intervals remains sensibly constant during the ordinary working day, and on this account the second base determination is of chief importance as a check on the first measurement.

Previous to the base being measured, the necessary precautions with regard to the temperature control are observed. Twenty-four hours before the verification, the testing room is closed, the fans set running, and the 4<sup>m</sup> rule carriage placed near the centre of the room with the casing removed so that the rule may attain the exact temperature of the surrounding air.

Value of One Turn of the Micrometer Screws.

Before measuring the pier intervals the value of one turn of each of the micrometer screws is determined. The microscopes at the ends of the carriage having been carefully focussed on the rule, measurements are taken on the millimetre intervals. Two observers simultaneously take part in the determination, their readings being noted by a recorder. After making five measurements of the millimetre intervals the observers change places, when a further five are made. The values of one turn of the micrometer screws are determined at the beginning and end of each base measurement. A record of such an observation is given in Table III. When the microscopes are being employed for intermediate graduations on the rule, in the case of measurements of intervals involving the use of the auxiliary benchmark, the value of one turn is found immediately after such measurements are made.

The micrometer screws have been carefully calibrated at the Surveys Laboratory and a correction table prepared which is used to obtain the corrected values of the micrometer readings for the computation of the test.

TABLE III

SURVEYS LABORATORY  
VERIFICATION OF COMPARATOR BASE  
Value of One Turn of Microscope Screw

Date.....Feb. 27, 1918.  
Observers.....W. W. D. & W. G. H.  
Computed by....W. W. D.  
Temp.....17°C.  
Recorder....R. H. F.

AT BEGINNING OF VERIFICATION

Microscope A					Microscope B			
Observer	W. W. D.		W. G. H.		W. G. H.		W. W. D.	
	0	1 mm	0	1 mm	0	1 mm	0	1 mm
	18·967	28·990	18·954	28·999	19·203	29·182	19·202	29·178
	·971	·988	·958	·997	·201	·189	·197	·181
	·963	·991	·958	·994	·200	·187	·197	·177
	·960	·993	·956	·998	·200	·184	·202	·175
	·966	·996	·956	·998	·201	·184	·204	·179
Means.....			18·9609	28·9943			19·2007	29·1816
Corrected Means....			18·9609	29·0113			19·2007	29·1886
One turn in mm.....				0·0995				0·1001

AT END OF VERIFICATION

Microscope A					Microscope B			
Observer	W. W. D.		W. G. H.		W. G. H.		W. W. D.	
	0	1 mm	0	1 mm	0	1 mm	0	1 mm
	18·702	28·720	18·686	28·738	18·983	28·963	18·983	28·957
	·703	·723	·688	·736	·983	·966	·985	·962
	·702	·728	·687	·737	·987	·967	·990	·960
	·698	·723	·692	·737	·986	·969	·992	·959
	·696	·732	·694	·734	·987	·969	·995	·956
Means.....			18·6948	28·7308			18·9871	28·9628
Corrected Means....			18·6948	28·7468			18·9871	28·9708
One turn in mm....				0·0995				0·1002

Mean value of one turn from beginning and end of verification.

Microscope A .....0·0995 <sup>mm</sup>  
Microscope B .....0·1002 <sup>mm</sup>

Measurement of Pier Interval.

The pier intervals can be measured quickly by experienced observers, and during the time of a complete base measurement the change in temperature of the rule is very small, the corresponding change in the 4<sup>m</sup> length during an average determination amounting to less than 0.5μ. The two observers, one at each end of the carriage, carefully bring the rule close to the benchmarks and to the same level. The means for these adjustments have been already described in connection with the description of the 4<sup>m</sup> rule carriage, *see* Fig. 17. Having placed the rule correctly relative to the benchmark graduations, it is only necessary to measure the distance between the rule graduations and the nearest benchmark ruling. After the first five of the ten measurements are completed the usual interchange of positions is made by the observers, to eliminate personal equation. The temperature of the rule is read twice, before and after the micrometer measurements. The readings obtained during a typical measurement of a pier interval, together with the necessary computation, are shown in Table IV.

TABLE IV.

SURVEYS LABORATORY

VERIFICATION OF COMPARATOR BASE  
Base Measurement

Date.....Feb. 27, 1918.  
Observers.....W. W. D. & W. G. H.  
Computed by ....W. W. D.  
Recorder....R. H. F.

8<sup>m</sup> PIER TO 12<sup>m</sup> PIER

Observer	Microscope A			Microscope B			Thermometers		
	W. G. H.			W. W. D.			No.	Reading	Corrected Reading
	Rule (turns)	Bench (turns)	R-B (turns)	Rule (turns)	Bench (turns)	R-B (turns)			
	18.692	18.888		18.980	18.980		38042	16° 90	
	.691	.892		.977	.980			.90	16° 75
	.685	.894		.977	.976				
	.687	.894		.975	.974		38043	16.79	
	.687	.896		.977	.978			.80	16.67
Means.....	18.6884	18.8928		18.9772	18.9776		Mean		
Corr'd do....	18.6884	18.8928		18.9772	18.9776				16.71
Do. in mm...			-0.2044			-0.0004			
			-0.02034			-0.00004			

Total (added to length of rule) ..... -0.02030<sup>mm</sup>

Observer	W. W. D.			W. G. H.		
	Rule (turns)	Bench (turns)	R-B (turns)	Rule (turns)	Bench (turns)	R-B (turns)
	18.684	18.900		18.982	18.982	
	.690	.900		.984	.984	
	.688	.904		.986	.977	
	.685	.897		.983	.986	
	.690	.903		.983	.981	
Means.....	18.6874	18.9008		18.9836	18.9820	
Corr'd. do...	18.6874	18.9008		18.9836	18.9820	
Do. in mm...			-0.2134			+0.0016
			-0.02123			+0.00016

Total (added to length of rule) ..... -0.02139<sup>mm</sup>  
Mean. Do. .... -0.02084

4<sup>m</sup> rule at 0°C..... 3.9999441  
Correction for 16° 71C..... +0.0001122  
Interval between rule and bench..... -0.0000208  
Interval 8<sup>m</sup> pier to 12<sup>m</sup> pier..... 4.0000355 metres.

### Measurement of Interval, Using Auxiliary Benchmark.

It has been shown in the description of the base that the permanent benchmarks are spaced at 4<sup>m</sup> intervals, and that an adjustable benchmark on the invar tube apparatus is employed when a distance is required which is not an exact multiple of 4 metres. Consider as an example a tape 100 feet in length (or expressed in metres 30.47997). There is a remainder of 2.47997 metres after deducting the nearest multiple of 4 metres less than the length required. This is the actual distance, to the nearest hundredth of a millimetre, laid off between the 4<sup>m</sup> pier and the auxiliary benchmark. The invar tube is set between the 0<sup>m</sup> and 2<sup>m</sup> piers and adjusted to bring the auxiliary benchmark in line, and at the same level as the permanent benchmarks. By means of the scale on top of the tube, the benchmark bracket A, Fig. 14, is clamped in its approximate position. The microscopes having been previously adjusted over the proper graduations on the rule, the carriage is brought up and adjusted, as mentioned above, so as to place the rule in the correct position. The final setting of the auxiliary benchmark is then made by means of screw J, Fig. 15. The actual interval is measured in the same way as the regular pier intervals.

### Variation in the Length of the Base.

It will be seen from the foregoing description of the base that the construction, with piers isolated from the floor and running down to a monolith some distance beneath the ground level, makes the length of the base practically independent of the room temperature. While this design gives a far more constant length than would otherwise be the case, it was to be expected that the annual periodic variation of temperature at the depth of the monolith, would affect the base.

In order to obtain information on this point, and to study other characteristics of the 32<sup>m</sup> base, the length was determined weekly over a period of more than two years.

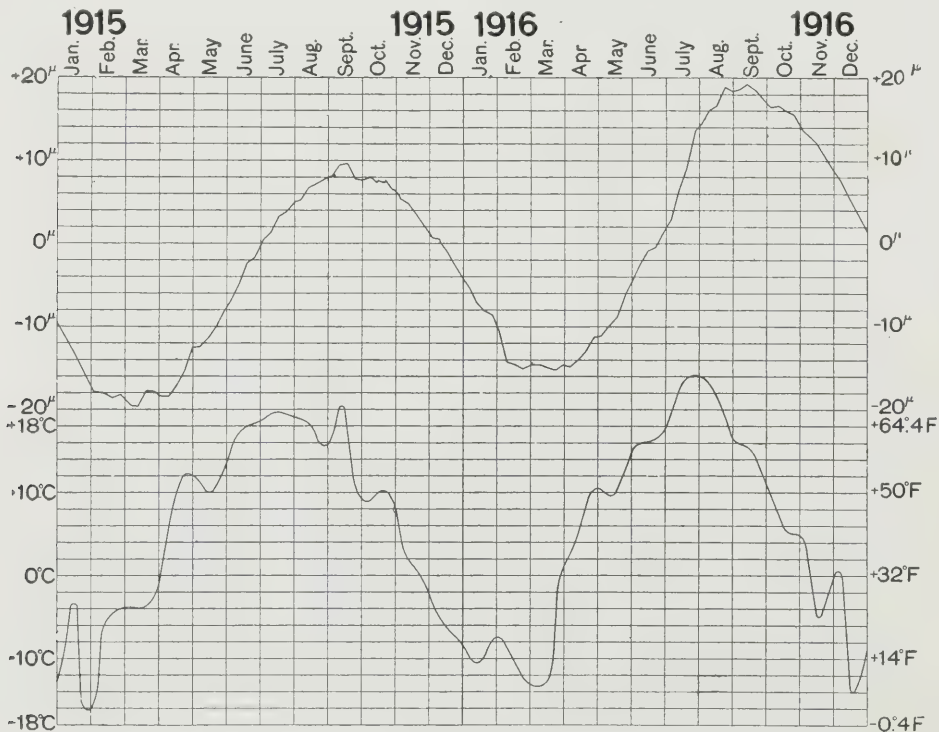


FIG. 31—Annual Variation in Length of Base  
Upper curve shows length of base. Lower curve shows outdoor temperature.

Fig. 31 represents the results obtained for the years 1915 and 1916, in graphical form. The curve is plotted to show the variation in length of the base in microns per metre. For the purpose of comparison, the outside temperature during the same period is also plotted. The general similarity of the two curves is at once evident. It will be noticed that a lag of about six weeks occurs between the length of the base and the outside temperature curves. This is what would be expected if the length were dependent on the temperature of the monolith, and, in order to obtain further information on this relation, three holes have been drilled in the monolith to receive thermometers. At the present time the temperature observations have not been conducted over a sufficiently long period to permit of any reliable data being obtained. In studying the base curve it will be seen that the maximum variation, between the greatest and least lengths of the whole base during the year only amounts to about one millimetre.

No two weekly determinations show a greater range than  $130\mu$ , corresponding to a maximum rate of change of only  $19\mu$  per day or less than 1 in 1,600,000. Hence it will be seen (as stated above) that no appreciable error is introduced in assuming the length to be constant for some hours, subsequent to standardization.

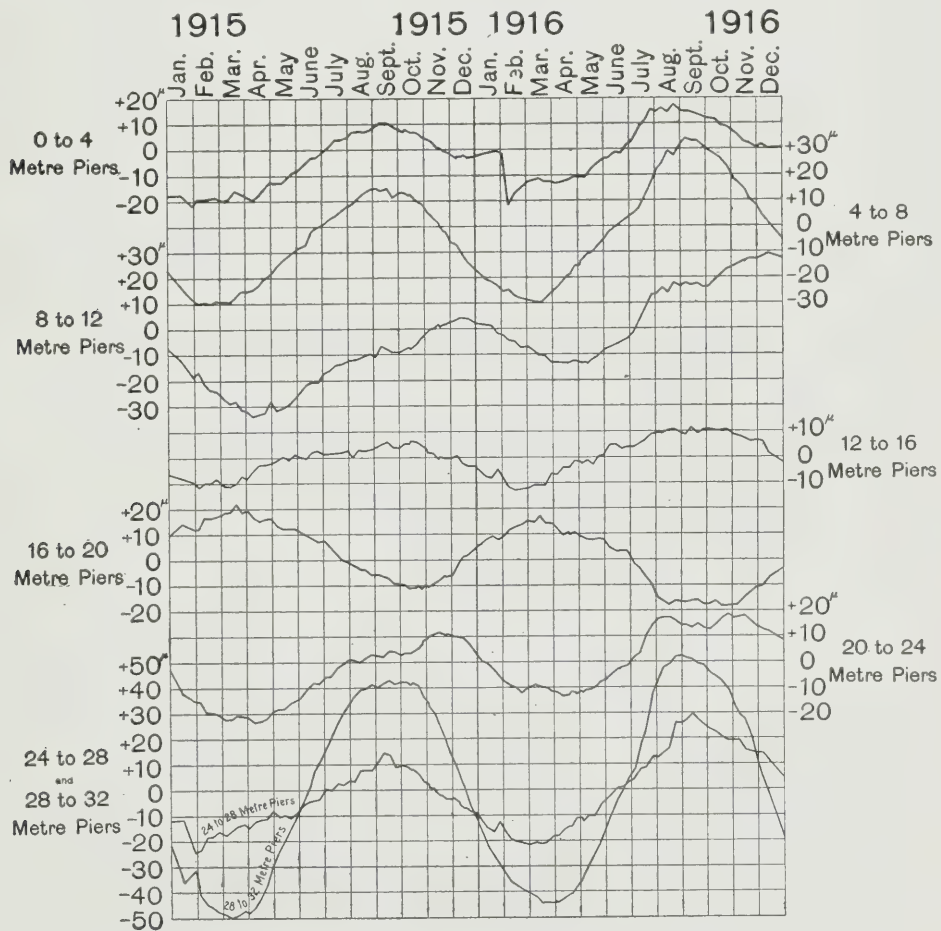


FIG. 32—Annual Variation of Spacing of 4<sup>m</sup> Piers

Fig. 32 shows the variations of the individual pier intervals of the base during the same period; these are also plotted in microns per metre. Generally speaking, with the exception of the 16<sup>m</sup>–20<sup>m</sup> interval, which moves in the opposite direction to the remaining intervals, the curves are similar in form to that for the whole base. Another point of interest is the greater change taking place in the 28<sup>m</sup>–32<sup>m</sup> interval, which may possibly be due to the fact that the ground surrounding the building at that end is more exposed to atmospheric conditions than at the other.

## COMPARISON OF MEASURES WITH THE BASE

Measures of length may be verified by either of two methods. In the first of these, the base apparatus is mainly employed to standardize the Laboratory steel standards, and invar tapes. In the second, steel tapes and other measures received for test are in practically every case compared with the Laboratory standards on the tape comparator. This latter method, it will be shown below, in the case of such tapes gives a degree of accuracy much higher than is necessary in practically all cases, and enables comparisons to be made in a minimum of time. The Laboratory standards used on the tape comparator are periodically compared with the base, and when not in use remain suspended from the racks.

The procedure in comparing a tape with any interval on the base is as follows. The tape having been suspended in front of the benchmarks, the end supports (and intermediate pulleys, when the length is required on the flat) are adjusted to bring the surface carrying the graduations to the same level as the bench marks. It is usual, in the case of steel tapes, to allow the tape to remain for a time before the readings are made, to ensure that it attains the same temperature as that of the adjacent thermometers. Two observers then make the determination. The first observer A, at the zero or fixed end, by means of the longitudinal adjusting screw, brings the tape graduation into line with the central ruling of the benchmark. Observer B, at the other end, then estimates the distance between the adjacent graduations on the tape and benchmark. Ten comparisons are made, observer A setting the tape each time. The temperature is then read from the thermometers along the track, and the observers having changed places, ten further readings are taken. To eliminate the friction error, settings are made alternately with the tension weight rising and falling.

When the length of the tape is required on the flat, the correction due to the sag, while it is supported on the pulleys, is computed from the weight per unit of length, this being obtained by weighing the whole tape on one of the Laboratory balances. A correction is applied for the weight of the end clips, and when these are of unknown weight, the weight per unit of length is obtained by calipering the tape with a micrometer gauge.

## USE OF THE TAPE COMPARATOR

The tape comparator affords a reliable method of rapidly and accurately comparing tapes and other measures with the Laboratory standards. When employed for steel tapes the very exact precautions with regard to temperature control and measurement taken when comparing steel standards with the base, are unnecessary. Both tape and standard are of steel and any slight variation in temperature will affect both by the same amount. The insulation of the building and method of temperature control is such that the test may be conducted at or close to, the standard temperature (62° F.). The lengths of steel tapes are usually required on the flat and by choosing standard tapes of nearly the same cross section as those being verified no account need be taken of the variation in length due to the difference in sag of the two tapes, owing to the small spacing (usually 100 inches) between the supporting pulleys. The length of the steel standard being known at the standard temperature, that of the tape under test for the same temperature is immediately obtained from the micrometer measurements, no further correction being necessary in all ordinary cases. Tapes may also be verified when supported in a single catenary, or at any desired intervals. The procedure in making the measurements is exactly similar to that previously described in reference to tape standardization on the base, with the exception that the settings and measurements of the intervals between the graduations

on the tape and on the standard are made by means of the measuring microscopes. It is easily seen that by slight modifications and temporary additions, this apparatus is adapted for comparing various other forms of subsidiary standards of length with the Laboratory standard tapes.

#### CONCLUSION

It was remarked previously that the building and apparatus here described although primarily intended for standardizing measures of length for the Topographical Surveys Branch, was also capable of undertaking work of a much more general nature. That facilities of this kind were needed in the Dominion was evidenced by the fact that, within a short time of the installation of the apparatus, many requests for the standardization of tapes and measures of various kinds were received from engineers, manufacturers and others.

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## BULLETINS

ISSUED BY

THE LABORATORY OF THE DOMINION LANDS SURVEYS  
DEPARTMENT OF THE INTERIOR

41. Tests of Small Telescopes at the Laboratory of the Dominion Lands Surveys
42. The Testing of Aneroid Barometers at the Laboratory of the Dominion Lands Surveys.
43. The Testing of Timepieces at the Laboratory of the Dominion Lands Surveys.
44. Standardization of Measures of Length at the Laboratory of the Dominion Lands Surveys.
45. The Testing of Thermometers at the Laboratory of the Dominion Lands Surveys.









